#3 Nov 1987

MONANA

JOURNAL of the AUSTRALIAN METEOROLOGICAL ASSOCIATION (INC.)

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Vol. 3 No. 3. November, 1987

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EDITORIAL NOTE

It is pleasing once more to produce MONANA after the hiatus in the affairs of the Society which produced a virtual standstill between 1982 and 1986.

For librarians and anyone else who may be interested, the publication history of Monana is as follows:

Vol. 1.	No. 1.	dated August	1969
	2.	" July	1970
	3.	" February	1971
	4.	" October	1971
	5.	" September	1972
	6.	" December	1972
Vol. 2.	No. 1.	" January	1974
	2.	" September	1975
	3.	" September	1976
	4.	" September	1977
Vol. 3.	No. 1.	" November	1978
	2.	" November	1979

It seems logical to settle on the precedent of Volume 2, that is one Volume over a 4 year period, and with one Number per year. This is the intention of the present committee. Accordingly, this issue is Vol. 3., No. 3., dated November, 1987.

It is not always easy for an editor to obtain material suitable for printing in a Society journal. As stated in the President's Report, it is our intention to publish the talks given at our meetings. This is not always possible, for example where a talk is very heavily reliant on pictorial 35mm slides or overhead projection transparencies which are expensive to reproduce for printing. This was the case with at least one meeting whose report we would like to have included. Another example would be the case of a 'chart drawing' meeting, whose proceedings are not suitable for publication.

I would therefore invite members to submit articles for inclusion in future issues as 'insurance' in the case where meeting reports may be unsuitable for publication. It must be understood, however, that first priority must be given to reports of meetings.

Articles should be typed using the format employed in this journal.

Any correspondence relating to MONANA, or articles for potential publication

should be addressed to

The Editor, MONANA,
Australian Meteorological Association,
c/- Bureau of Meteorology,
25 College Road,
KENT TOWN S.A. 5067

Finally, I would like to thank the authors of the following fascinating articles and wish members joy in reading them.

W. Slaytor
Editor

November 1987

AUSTRALIAN METEOROLOGICAL ASSOCIATION INCORPORATED

PRESIDENT'S REPORT FOR 1986-1987

(Delivered to the Society on 19 August, 1987)

The Australian Meteorological Association was formed in Adelaide in 1969 with the objective of bringing together people who are interested in meteorology.

No academic qualifications for membership are required and all the talks given are made as non-technical as possible. However, at times it is necessary to introduce some technical explanations for unusual meteorological situations.

Speakers at our meetings have come from all walks of life; the programme has included a professional fisherman, a research worker on tides and ocean waves, and a Forestry Fire Protection Officer as well as experts in gliding, air pollution and other subjects on which the weather has direct bearing.

Meetings are presently held at two-monthly intervals and the association publishes "Monana" a journal which contains reports of our meetings as well as other typical weather material. Meetings are held in the Conference Room of the Bureau of Meteorology located at 25 College Road in Kent Town.

Due to problems largely associated with obtaining a suitable secretary/treasurer, the association went into recess in 1983.

The association began holding meetings again early in 1986, and on 20 August of 1986 the first Annual General Meeting after 1982 was held at which a new committee was elected. Details of the committee, last year's program, membership and so on, follow:

1 COMMITTEE

The present committee, which was voted into office for a period of two years consists of:

President:	Dr. John Noye
Vice President:	Mr. Allan Brunt
Secretary/Treasurer:	Mr. Peter Webb
Six committee members:	Mr. Graeme Furler, Mr. Bill Slaytor, Mr. Lynn Mitchell, Mr. Adrian Gordon, Mr. Warren Wright, Mr. Terry Keen

2 THE YEAR'S PROGRAM

The program of speakers during the last 12 months was:

20 August 1986:	"Research projects in the Bureau of Meteorology" by Mr. Warwick Grace
15 October 1986:	"Climate response to solar variability evidence from the geological record" by Mr. George Williams
18 February 1987:	"Weather associated with the British atomic tests" by Mr. Adrian Gordon
15 April 1987:	"VHF Radar and its future applications" by Mr. Andrew Watson
17 June 1987:	"The Greenhouse Effect" by Mr. Graeme Crooks

There was an average attendance of 25 at these talks.

Future speakers and their topics include tonight's speaker:

19 August 1987:	"Meteorological optics of a UFO kind" by Mr. Allan Brunt
28 October 1987:	"The Adelaide Gully Wind" by Mr. Ian Holton
17 February 1988:	"Seabreezes in Adelaide" by Mr. Warwick Grace
13 April 1988:	"The R101 airship disaster" by Mr. Adrian Gordon

3 MEMBERSHIP

Our membership at present totals 71, consisting of 48 full members, 12 affiliate members, 4 pensioners, 6 students and 1 junior member.

The aim is to again reach the figure of 100 which existed before the association went into recess at the beginning of 1983. If you know of anyone interested in joining the association please invite them to one of our meetings so we can meet them and they can enjoy the talks given.

4 FINANCIAL STATEMENT

Because membership fees for the two years 1986-87 were collected in 1986, only fees from new members were collected during the last 12 months. Consequently, since that last annual general meeting there has been an excess over income of $177.56 spent during this period. However, the finances are in a sound state, the balance of accounts being $1431.11.

At a recent committee meeting it was regretfully decided that membership fees had to increase, after thirteen years without change. The new fees

are:

Full member	:	$8.00
Affiliate	:	$4.00
Student	:	$2.00
Junior	:	$2.00
Pensioner	:	$2.00

However, those who attend our meetings and enjoy the free tea/coffee and biscuits afterwards, will agree that these amounts are very reasonable.

5 MONANA

For the first time since 1982, the association journal, "Monana", will be published again this year. The new editor, Mr. Bill Slaytor, is working hard preparing the material given to him so it is suitable for publication. From now on it is the aim of the committee to issue this journal on an annual basis.

6 ACKNOWLEDGEMENTS

Special thanks must go to a number of people. Firstly, I wish to thank all speakers for their excellent presentations. Secondly, I thank all those members who braved the rain and cold to attend our recent meetings: our last meeting had the best attendance for the past 12 months. Thirdly, our energetic secretary/treasurer, Mr. Peter Webb, continues to issue and circulate newsletters with meeting notices, which is no small task. Anyone with short items of interest is welcome to approach Peter in case he can use them. And I would like to thank Mr. John Armstrong for carrying out the secretarial duties when Peter cannot attend meetings. Finally, my thanks go to the Regional Director of the Bureau of Meteorology in South Australia, Mr. Graeme Furler for the assistance he has given the association.

19 August, 1987

John Noye,
President

UNDERSTANDING UFOs

A.T. BRUNT

INTRODUCTION

After 38 years in meteorology, it is only natural that I should have strong views on the subject of unidentified flying objects which, as a name, is quite misleading, as most of them have been identified. Popular use has changed the meaning of the term to refer mainly to extra-terrestrial visitations.

Some workers in the field of Ufology (commonly called Ufologists) started with the extra-terrestrial hypothesis (E.T.H.) but over the years have become increasingly disenchanted with it. We now have a new breed of Ufologists who believe that UFOs are "metaphysical", "supernatural" or "interdimensional" instead of extra-terrestrial spacecraft. For example, some of the newer descriptions of UFOs are:

(i) They are omnijective and willed into physical existance.

(ii) They are objective manifestations which are psychokinetically generated by-products of unconscious processes. (whatever that means)

Despite the large monetary rewards offered, there have been no scientific demonstrations of the paranormal, and this includes attempts in various fields such as spoon bending, pyramid power, levitation, psychic surgery etc. The paranormal explanation for UFOs seems to be at odds with the E.T.H. when it comes to such things as marks on the ground and alleged abductions. So there is disagreement amongst Ufologists and sometimes marked changes in their beliefs. Even the guru of ufology, Dr. Hynek, no longer believes in the extra-terrestrial. He said, in the February 1985 issue of Omni Magazine, that "My biggest hope is that as the research progresses, I will be able to demonstrate that the E.T. hypothesis is untenable, that it just doesn't wash to a scientist".

EYEWITNESS TESTIMONIES

Most UFO evidence is of the eyewitness kind. Although eyewitness accounts are considered to provide important evidence, most people are not aware of the unreliable nature of such evidence. When a number of observers witness an unexpected, dramatic or startling event, there are usually considerable differ-

ences in their reports of that event. The more time witnesses have to think over and talk about what they have seen, the less accurate their memories become. Sightings, like wine, tend to improve with age. So it is important to get details very soon after the event.

Psychologists have shown that the reliability of witnesses is not dependent on socio-economic status or on the confidence of the observer. A university education, a respectable career or training as a pilot is no guarantee of reliability when observing some startling or unusual event. Psychologists are also agreed that any observer is less capable of remembering details and less accurate in reporting when under stress.

It should be pointed out that, as an instrument, the eye is not foolproof: actually, it is an imperfect optical system. Light waves not only have to pass through the lens and fluids of the eyeball, none of which allows a perfect transmission of light, but also on the inside of the eye have to go through a network of cells and blood vessels before being changed to messages for the brain. For this reason, there are many people with visual defects such as near-sightedness, but even with normal vision, there are other influences which can affect the way objects appear to be. The most common of these influences are :-

(i) the autokinetic effect - apparent movement of objects which are known to be stationary.

(ii) after-images - a retinal image which persists after the retina has been exposed to a light which is no longer seen. It is such persistance of vision which makes it possible for us to easily view movie film.

What the eye sees is also affected by the brain; what the brain tells you you ought to see. For example, members of the Loch Ness Investigation team, who believed in the existence of the monster, took photographs of what they thought were "humps ploughing through the water". However, when the photographs were developed, they showed no humps, only a slight wake in the water. So, seeing is not always believing. Sometimes it is the reverse, even allowing for such optical traps as mirages.

PRE-REQUISITES IN UFOLOGY

Workers in Ufology, whether E.T.H. or paranormal believers, should always bear in mind the unreliability of eye witness testimony. They should also have a

wide knowledge in a number of scientific disciplines so that natural phenomena and man-made objects can be eliminated in the consideration of any particular case. To my mind, this knowledge should include:-

(a) Radar - with a particular knowledge of anomalous propogation and angels.

(b) Astronomy - with a knowledge of how the appearance of the moon, planets and meteors can deceive even the most reliable of observers.

(c) Meteorology - particularly in the area of meteorological optics.

(d) Space Technology - particularly with regard to re-entry into the atmosphere.

(e) Psychology - as to why so many hoaxes have been perpetrated.

(f) Geology - a knowledge of piezoelectric effects with earth tremors in mineral or quartz bearing rocks.

(g) Ornithology - how flocks of birds have been called UFOs.

(h) Entomology - the origin of Angel Hair and the types of insects which build circular nests.

(i) Botany - particularly the growth of fungi in circles.

(j) Veterinary Science - re mutilations and unusual marks on cattle.

ERRORS IN IDENTIFICATION

I have a list of over 100 different phenomena or man-made objects which have, at some time or other over the last 30 years, been incorrectly called UFOs. The most common of these are as follows:-

1 Clouds

(i) Lenticular clouds - grey, lens-shaped and sometimes laminar in appearance. The fact that they can remain stationary when other clouds are moving has confused some Ufologists.

(ii) Mother-of-pearl clouds - caused by the sun shining on fine ice clouds high in the stratosphere up to a few hours after sunset.

(iii) Noctilucent clouds - the sun shining on meteoric dust high in the stratosphere, again up to a few hours after sunset. A feature is

their apparently rapid movement, suggestive of space travel, as the sun sinks further below the horizon.

2 Electrical Phenomena

Separation of charges from the normal electrical field which exists in the atmosphere takes place in the following cases:

(i) St. Elmo's Fire - commonly forms on the leading edges of ships or aircraft as they move through an electric field. A Pillar of Fire is a form of St. Elmo's Fire caused by dust particles in dry areas.

(ii) Lightning - It should be noted that there is a rarer form of lightning which floats slowly as a small red or orange ball. It is called ball lightning and it leaves a burnt ring when it hits the ground.

3 Optical Phenomena

(i) Haloes - refraction of light through ice crystal clouds. Small sections look silvery white.

(ii) Corona - diffraction through fine water droplets. Segments of these are called irridescent clouds. Again small sections look like UFOs.

(iii) Glory - coloured circles round the shadow of an object, e.g. round the shadow of a plane on underlying clouds. Really an anti-corona.

(iv) Scintillation - the apparent changes of size, shape, position and colour of objects caused by the refraction of light through air of differing densities.

(v) Auroras - radiative emission from nitrogen and other molecules during magnetic storms. Auroras take on many dramatic forms, such as curtains, searchlights, ladders and fireworks but the most easily confused is the auroral meteor.

(vi) Mirages - often a cause of confusion as, due to refraction, light waves are bent upwards when steep lapse rates exist and bent downwards when marked inversions (temperature increases with height) exist. We are all familiar with the former type of mirage, e.g. water on the road on a hot day, but few people realize that the latter give rise to objects on the ground or over the horizon appearing to be in the sky. Surface inversions can be found on clear, calm and cold nights and these can produce a variety of localised mirages, e.g. trains,

ships or semitrailers in the sky. A widespread inversion, such as the subsidence inversion in marked ridges of high pressure, can extend for hundreds and sometimes thousands of kilometres. When this occurs, super-refraction enables light waves to be bent round the earth's surface for remarkable distances. Objects have been identified from sea level at distances of 1000km, even further from an aircraft, as the atmosphere acts as a magnifying lens at this time. The Flying Dutchman (a ghostly sailing ship) was obviously a good example of this type of mirage.

(vii) Parhelia, mock suns, sun dogs, sun pillars, the green flash and crepuscular rays are other optical phenomena.

4 Astronomical Phenomena

Under certain circumstances, the planets and stars can all take on an unusual appearance which can fool experienced observers. Even a scientifically trained naval officer, who later became President of USA (Jimmy Carter), has demonstrated that he can mistake a bright Venus for a UFO. During World War II, US gunners tried to shoot down Venus (thankfully without success).

Meteors, material bodies which enter the earth's atmosphere from outer space, are called shooting stars when they are faint, but the brighter ones are called bolides or fireballs. Bright meteors are particularly spectactular when viewed from a plane. The pilot generally concludes that the meteor is very near, or about to hit the aircraft, but in fact it can be 100 to 150 km away. Meteors have been measured to move quite slowly (10 km per sec) and on rare occasions have been observed for 2 or 3 minutes. They usually look like a grey, wingless aircraft with green colouring.

5 Man-made Objects

(i) Satellites - there are currently over 5200 man-made objects of this type circling the earth. Their entry into the atmosphere is usually fiery with long smoke trails.

(ii) Balloons - the 6 hourly release of meteorological balloons from 50 different places in the Australian region provides a frequent cause for confusion. They all carry a radar target and some a radiosonde transmitter. Larger research balloons (Hibal and Ghost Balloons for example) also give rise to a spate of UFO reports as some are as tall

as a 10-storey building. Winds in the upper air are usually different from the surface wind, a fact which often leads to confusion in identification as it appears that the light is being propelled against the wind.

6 Radar Observations

Every radar operator knows of the false echoes or 'angels' which can occur, even with the most modern equipment. The truth is that radar waves are subject to the same refraction and reflection conditions as light waves and they may be bent round the earth's surface to produce radar mirages. Sharp temperature and humidity discontinuities, typical of widespread subsidence inversions, set up what is known as radar ducting. As an example, a cruiser using radar in the Mediterranean during the World War II, reported sinking a target that later proved to be a false image of Malta, which was at the time well beyond normal radar range.

Single or multiple reflection of radar waves from other reflection surfaces can give rise to ghosting. For example, a plane approaching an airport can have a ghost image flying behind it, often at twice the speed, but the ghost invariably disappears when the plane lands.

Ufologists often give the most weight to radar as evidence for the existence of UFOs but they seem to ignore the known limitations of radar. When there is no visual sighting to confirm the radar echo, they claim the UFO must be able to make itself invisible. When there is no radar echo to confirm a visual sighting, often the case with optical phenomena, they say the UFO has made itself invisible to radar. Great science fiction material!

RESULTS OF OFFICIAL SURVEYS

Official UFO records were maintained in Australia by the RAAF for 12 years and in USA by the US Air Force for 22 years. Each of these records show that approximately 97% of cases were identified as natural or man-made phenomena. Of the remaining 3%, some were unidentifiable because of lack of important data such as date or time, and some were hoaxes perpetrated by people who like to spin tall tales, taking great delight in fooling the news media or wanting to become instant celebrities. Both the RAAF and the US Air Force have discontinued their official surveys as they can see no value in continuing them.

The conclusions of Project Blue Book (USA) were:-

(i) No unidentified flying objects reported, investigated and evaluated by the Air Force has ever given any indication of threat to our national security.

(ii) There has been no evidence submitted to or discovered by the Air Force that sightings categorized as unidentified represent technological developments or principles beyond the range of present-day scientific knowledge.

(iii) There has been no evidence indicating the sightings categorized as unidentified are extra-terrestrial vehicles.

UFO PHOTOGRAPHS

Often the photographer comments that "he didn't see anything unusual at the time" when oddly shaped saucer-like objects appear on the developed photograph. Processing defects are much more common than most people realize; a drop of chemical or a crease in the film can easily give rise to unexpected objects on a photograph. Unexpected luminous objects on a photograph are usually caused by lens flare; these happen when a very bright light (the sun or a studio light) is reflected several times off the different elements inside the lens. You can see examples of lens flare on your TV screen.

It is easy to create fake UFO photographs and many have been identified as such. Of all the thousands of "genuine" UFO photographs, there is not one that shows a clear, unambiguous flying saucer. Most show only a blip, distant dot, a blur or a line.

STANDARD UFOLOGIST ARGUMENTS

(i) By quoting only conclusion (i) of Project Blue Book, the impression is given that the official view is "they are there, but they are friendly".

(ii) Scientists have closed minds. The usual example quoted is when the French Academy of Science disbelieved reports about stones falling from the sky. However, Ufologists conveniently forget that the French Academy reversed its decision within 30 years when stones from many areas were analysed, i.e. when 'hard' evidence became available.

(iii) The fact that 3% of cases are unidentified is used as evidence for extra-terrestrial visitation. However, a goodly sample of the population (97%) is prosaic in nature and there is no specific reason for deducing that the remaining 3% are anything else.

(iv) The onus of proof is shifted to the negative side. It is well nigh impossible to scientifically prove that something does not exist.

(v) Governments and officials are covering up. Of the 80,000 pages of UFO material released in USA after the Freedom of Information law was passed, only 176 pages (or 0.2%) are restricted. 176 pages from a Government Dept. in 30 years is a very insignificant amount if, in fact, it dealt with earth-shattering news like space men landing in USA. The truth is that this part of the material is restricted because it contains some agents names.

ABDUCTION CASES

Hundreds of people throughout the world have claimed to be abducted by UFOs. Most of these were in USA and a few claim to have been abducted up to 4 times (some form of discrimination there). However, not one has passed an independent polygraph (lie detector) test and not one of the US cases has reported their abduction to the FBI, which has a penalty of $10,000 or 3 years gaol for false claims of this type. The reports are invariably given to the news media. Ufologists argue that the veracity of the claims is supported by hypnosis, yet psychiatrists say that people can lie under hypnosis and relive fantasies. It should be noted that this method of obtaining the truth is not used in law courts throughout the world.

REASONS FOR POPULAR BELIEF IN UFOs

(i) The news media give publicity to sightings and little or no publicity to explanations.

(ii) The flood of UFO books. Very few of these have any scientific content and most are completely subjective. There is a dearth of explanatory books in school or public libraries; in fact, they cannot be bought off the shelf but have to be ordered (if you know about them).

(iii) Lack of knowledge of the wonders of our atmosphere and their bizarre effects.

(iv) The prize monies offered by the news media in USA.

(v) TV and some films divorce people (especially children) from reality.

CONCLUSIONS

The evidence for the existence of UFOs as extra-terrestrial or paranormal spaceships is very meagre. Let us examine the case for and against:-

	EVIDENCE FOR UFOs (As presented by Ufologists)	EVIDENCE AGAINST UFOs (As presented by science)
1.	Nocturnal lights.	There are many causes for unusual lights at night time, or even during the day.
2.	Unusual movement of lights. Rapid changes of speed or direction.	This is typical of optical phenomena, especially when the observer is moving.
3.	Radar echoes.	Radar literature contains many examples of anomalous propagation, angels or ghosts.
4.	Marks on the ground.	Some insects and fungi cause circular marks on the ground. Ball lightning can leave a burnt circle.
5.	Alleged abductions.	No 'abductees' have passed an independent lie-detector test. Many have relived their stories under hypnosis.
6.	Stalled vehicles.	Motor mechanics know of many causes for vehicles to stall.
7.	Mutilated cattle.	There have been no cases of a veterinary pathologist being unable to explain markings on cattle.
8.	Earth tremors.	Geologists tell us the piezoelectric lights are caused by some earth tremors. The lights (UFOs) do not cause the tremors.

It does seem that this type of evidence would not be acceptable in a court of law. In all the years of record since 1947, when the name UFO was invented, there is not one shred of hard evidence to support the claim that they are anything more than natural phenomena or man-made objects. In literally millions of weather observations, I know of only one case which included a supposed UFO. Parhelia, mirages, mock suns, haloes and ball lightning are all included in the observational records but UFOs are conspicuous by their absence. Ships Officers throughout the world keep a trained watch on the skies; they too see many optical phenomena but very few UFOs. The magazine 'The Marine Observer' gives hundreds of natural examples. Other professional "sky watchers", such as the astronomers at

Mt. Stromlo Observatory, have also reached the conclusion that, although some sightings may be bizarre and unusual, there is nothing in all the thousands of reports to support Ufologists' claims.

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SOUTH AUSTRALIA'S CLIMATE 2030:

THE GREENHOUSE EFFECT AND CLIMATIC CHANGE

G.A. CROOKS

INTRODUCTION

The theory of the Greenhouse Effect of Carbon dioxide (CO_2) in the atmosphere is that it acts as a transparent window to the short wave ultraviolet radiation from the sun but absorbs and retransmits the longwave heat radiation emitted from the Earth. In the equilibrium situation the incoming radiation is in balance with the outgoing radiation. This balance is disturbed by increasing the concentrations of CO_2 in the atmosphere so that more of the longwave radiation is absorbed by the atmospheric CO_2 with a subsequent increase in temperature.

The greenhouse gases are principally CO_2 but also include nitrous oxide, methane and chloro-fluorocarbons which are increasing as a result of industrialization.

The joint UNEP/WMO/ICSU conference in Villach, Austria in 1985 involving scientists from 29 countries reached the conclusion that increases in the atmospheric concentrations of CO_2 and the other greenhouse gases would be equivalent to doubling the concentration of CO_2 from pre-industrial levels by as early as 2030 AD.

The most advanced experiments with computer models of the earth's climatic system show increases in global mean surface temperature of between 1.5 and 4.5°C for the doubling of the atmospheric CO_2 concentration. However, because of the complexity of the climatic system and imperfections in the models, values outside this range of 1.5 to 4.5°C cannot be excluded. The realization of these changes will be slowed by the inertia of the oceans. The delay in reaching equilibrium is expected to be as long as two or three decades after the cause of the temperature rise has stabilized (Bryan et al 1982).

Based on observational data the estimated increase in global mean temperature during the last 100 years of 0.3 to 0.7°C is consistent with the projected temperature increase attributable to the observed increase in the concentrations of CO_2 and other greenhouse gases.

The early 1800 CO_2 concentration has been estimated to be of the order of 260 parts per million by volume (ppmv) (Wigley 1983) and observations in 1983 show CO_2 concentrations of 340 ppmv. This increase of about 30% is

attributable to the burning of fossil fuels as a result of industrialization and to the deforestation associated with agricultural expansion.

This implies that a 30% increase in CO_2 concentrations has given rise to a temperature increase of 0.3 to 0.7°. A time lag of about 25 years is necessary for thermal equilibrium to be achieved in the climatic system, so a real temperature rise at the upper end of this range, say, 0.7°C is not unreasonable to have occurred to date. The relationship between the increase in CO_2 concentrations and temperature rise is unknown, but if we assume a linear relationship, then we can give an estimate of the eventual temperature rise possible by doubling the CO_2 concentration. This leads to an estimate of about 2.3°C, which is well within the range estimated by the Villach conference.

SOUTH AUSTRALIAN PERSPECTIVE

The consequences of the Greenhouse warming as noted in the Villach Statement are as follows:

(1) The snowline will rise in the Australian alps. This will change the flow rhythm of the Murray River.

(2) A change in the distribution of rainfall will occur both across the state and during the year.

(3) The sea level will rise between 20 and 140 centimetres because of the thermal expansion of the water.

All of these changes will affect South Australia to some degree although the changes will have either beneficial or detrimental effects, or both.

(1) SNOWLINE CONSIDERATIONS

At present an average snowline in the Australian alps in winter is about 1400 metres (4600 feet). Each degree celsius rise in global temperature will lead to a rise in the snowline of 100 metres. If the global mean temperature rises between 1.5 and 4.5°C during the next 50 years as suggested by the Villach Statement, then the snowline will rise by 150 to 450 metres. A linear extrapolation of the temperature rise due to the change in CO_2 concentration leads to an overall temperature rise of about 2.3°C. Using this figure as a basis to estimate the change in snowline by the year 2030AD, it is estimated that the snowline will rise by about 230 metres. The snowline then will be about 1530 metres (5360 feet), or possibly higher. This is going to have a dramatic effect on the ski resorts of southeastern Australia since skiable snow is

usually a few hundred metres above the actual snowline. Mount Buller, for example, is 1806 metres high. With the snowline at 1630 metres, it may cease to exist as a viable ski resort.

For South Australia the rise in snowline will also have some effects, although they may not be as dramatic. Runoff patterns from the Alps will change because there will be a reduced storage capacity in the form of snow. The runoff will occur more or less as the precipitation falls instead of being stored until the spring melting of the snow. This will lead to a change in flow pattern of the Murray River system and may ultimately affect South Australia and the people who rely on it, including the Adelaide water supply and the irrigation areas all along the River. The result of this may not be detrimental but the changes in flow pattern may mean that some adjustments may need to be made to water storage and water usage.

(2) RAINFALL

Computer Climatic Models show that as the Global Temperature rises, the changes in temperature are likely to be larger at the poles and less at the equator. The result of this will be a change in the rainfall belts over the world with weather systems generally moving polewards with the expansion of the Tropics.

The westerly rainfall belt is expected to move southwards in the Southern Hemisphere and there will be more frequent incursions of Tropical moisture further south, particularly during the Summer months when the Tropics are most active. Over South Australia, then, rainfall may be expected to increase in the north because of the increased tropical activity and to decrease in the south owing to the westerly belt moving polewards.

Pittock (1975) described a change in mean annual precipitation for the periods 1913/1945 and 1946/74 which showed increases in rainfall over South Eastern Australia. He revised these figures in 1983 and attributed the changes in annual rainfall to the Greenhouse effect. Using district average rainfall figures for South Australia, the change in annual rainfall between 1913/1945 and 1946/1985 was assumed to have been caused by the 0.7°C global temperature rise of the greenhouse warming. The total warming expected by doubling the CO_2 concentration was calculated above to be about 2.3°C by 2030AD. Assuming a linear relationship between temperature change and rainfall change implies further change of about 2.25 times the change since 1945. The Annual rainfall figures could therefore change by as much as, (or even more than), the percentages shown in Fig. 1.

PERCENTAGE CHANGES TO AVERAGE ANNUAL RAINFALL
BETWEEN 1980 AND 2030 AD

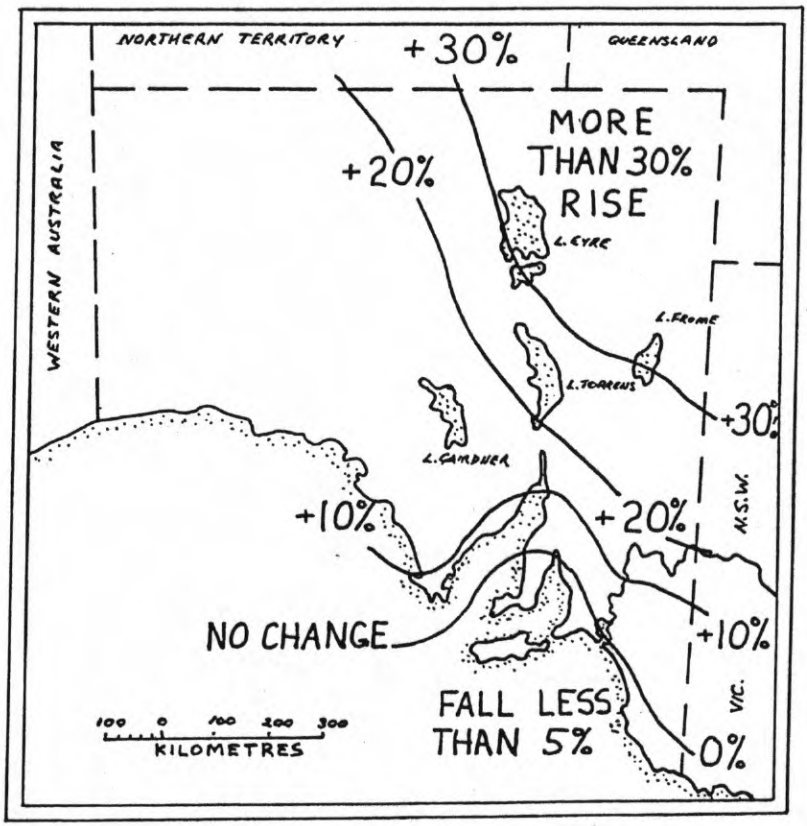

FIG. 1

SOUTH AUSTRALIA - ANNUAL AVERAGE RAINFALL ALL YEARS TO 1978

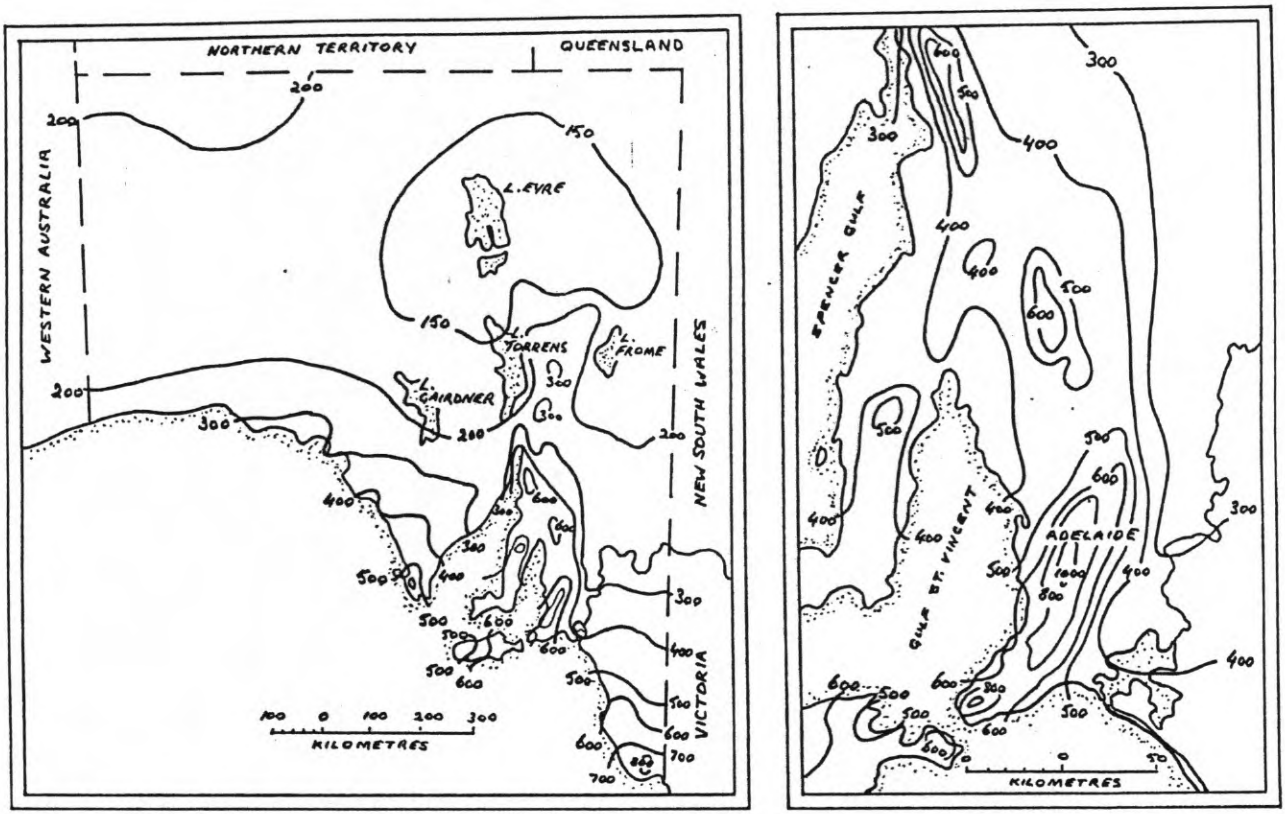

FIG. 2

SOUTH AUSTRALIA - ESTIMATED ANNUAL AVERAGE RAINFALL 2030 AD

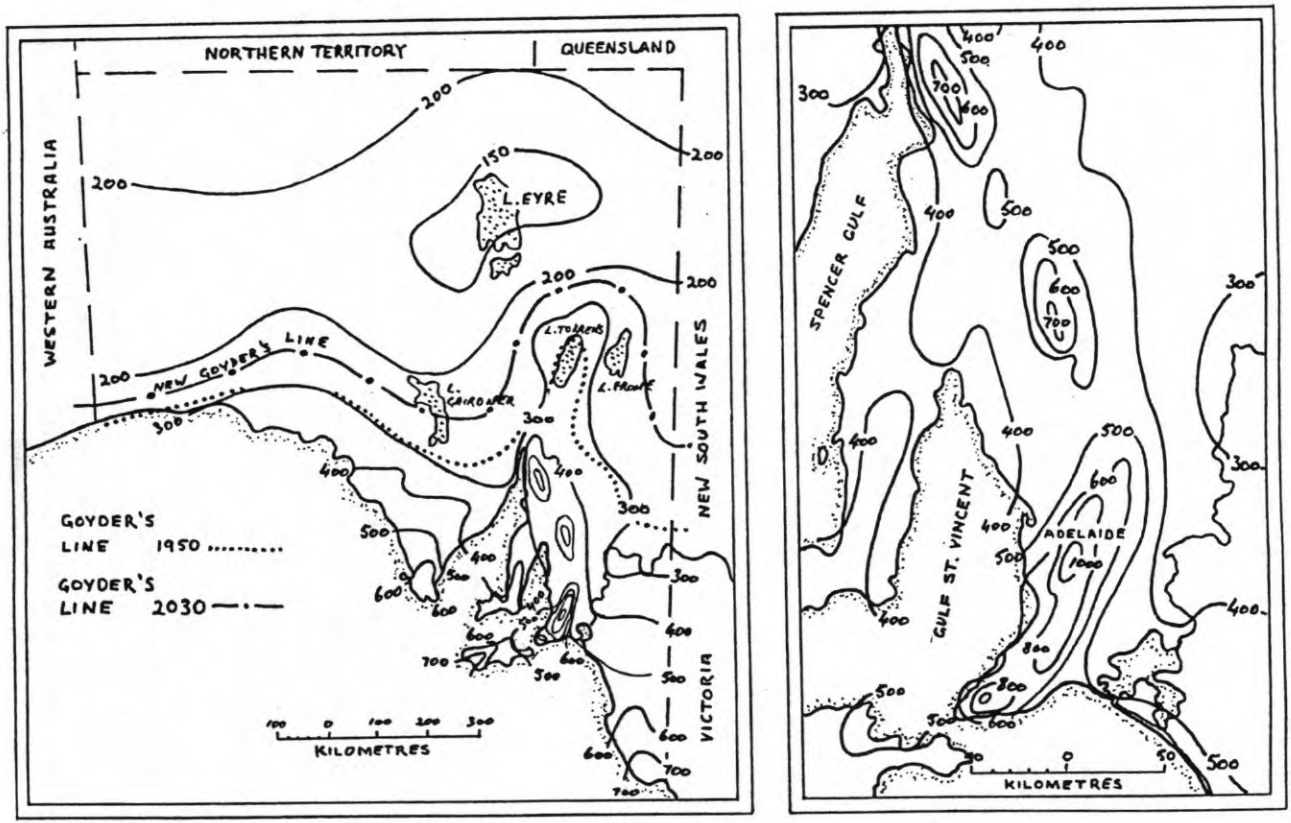

FIG. 3

Adding these changes to the current average annual rainfall map (Fig.2) gives a forecast annual rainfall map for South Australia for the year 2030AD (Fig. 3). It can be seen from Fig. 3 that the change in rainfall pattern will be generally beneficial to South Australia, however with the rain increases mainly during summer the actual usefulness will be hard to gauge.

Goyder's line, which coincides more or less with the 250mm rainfall line, may move north by 80 to 100km aiding the more marginal farm land in the Murray Mallee and Eyre Peninsula. The increase in the summer rainfall may not help the growth of crops at all however, but may increase problems such as pests (locusts) and diseases (rust) to the grain crops of these areas.

Another consideration with regard to the increased rainfall is that there will be a marked increase (perhaps as much as 50%) in rainfall over virtually all the catchment area of the Murray-Darling River system during Spring, Summer and Autumn, and slightly less rain in winter (Pittock 1983). This overall increase in rainfall over the catchment should result in increased flow of water down the Murray River in South Australia with a subsequent improvement in water quality in the South Australian region. There may still be some salinity problems over South Australia in the lower parts of the Murray because of the greater inflow of saline ground water into the river due to the rising water table.

(3) SEALEVEL CHANGE

(a) Storm Surges and High Tides

With the rise in global mean surface temperature, the sea will expand. The result of this thermal expansion will mean a sealevel rise of 20 to 140 centimetres. Using an average rise of about 1 metre, the sealevel rise will affect low lying coastal regions by increased storm surge flooding and wave damage, loss of fall in coastal drainage, loss of estuarine habitat and will jeopardise marinas, ports, resorts and coastal industries.

The whole of the gulfs will be at risk. A look back through press cuttings reveals frequent reports of storm damage in both gulfs, with jetties damaged, and extremely high tides causing flooding. The most recent events of this nature were in June and July, 1981, when very high tides, caused by a combination of a severe Southern Ocean storm and a high tide, were

reported at Outer Harbour, the inner harbour at Port Adelaide and at Port Pirie and Port Augusta. At Port Pirie on the 1 June, 1981 the tide peaked at 4.55m., very close to the record level of 13 August 1934. Only sand-bagging along the dockside streets prevented major flooding. On the same day Outer Harbour reported a tide of 3.94 metres, - the highest level recorded since records began in 1940. The inner harbour at Port Adelaide recorded a high tide of 4.0m., only just below the record height of 4.03m. recorded on 12 May 1960.

(i) Port Adelaide

Consider just Port Adelaide now. The lowest embankment in the Port Adelaide area is 4.1 metres. However, when the water level gets above 3.8 metres, the sea water is likely to flow up out of the storm water drains in the Port Adelaide area. The storm of June 1981 added 1.4 metres of storm surge to the high tide of 2.6 metres. The storm tide height of 4.0 metres was enough to flood some roads around the Birkenhead Bridge mainly due to the water flowing out of the storm water drains. It would have been much worse if it had also been a heavy rain situation because the rain water would have added to the flooding. This storm surge was caused by an intense Southern Ocean storm.

If we now consider a similar storm in 50 years time with a sealevel rise of about 1.0 metre, the high tide will reach 3.6 metres. The storm surge of 1.4 metres will mean a peak high tide of about 5 metres with wave heights on top of that.

At present, tides at Outer Harbour reach 2.6 metres several times a month. In 2030AD high tides of 3.6 metres will be reasonably common, which means that a storm surge of only 50 centimetres is likely to cause flooding. Any reasonable storm moving in from the southern ocean can lift the sea level in the Adelaide area by 50 centimetres (Vecchio 1980). Add to this then the local wind effect and the increase in sea level caused by the reduction in surface pressure and we will have potential flooding with every frontal system that crosses South Australia when it coincides with a high tide.

If nothing is done to raise the Port Adelaide embankments and safeguard all the low lying areas, then the erosion from the frequent storm surges will destroy the levees and Adelaide may have a new coastline in 2030AD. On the map of Port Adelaide (Fig. 4), if mean sea level is raised by 1.0 metre

PORT ADELAIDE 2030 AD?

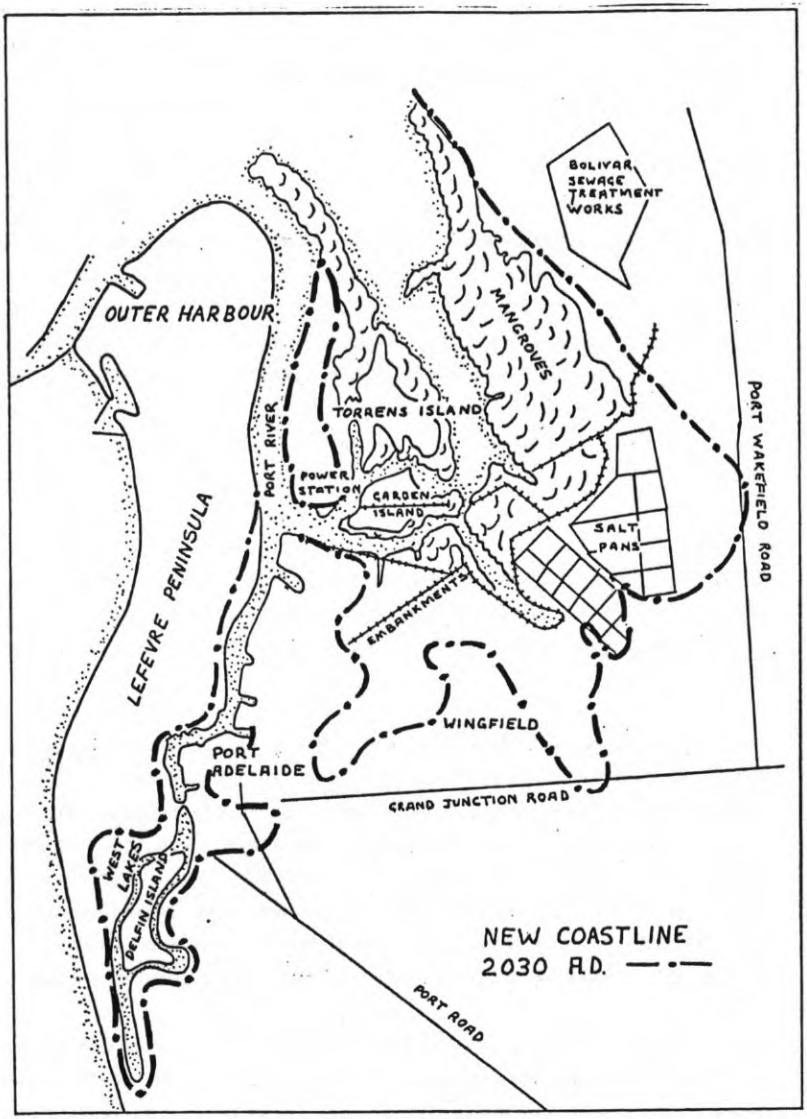

FIG. 4

by the year 2030AD and there is a storm surge or a high tide of 1.0 metre above the mean sea level datum, the sea will have risen 2.0 metres above the present mean sea level. Joining the 2.0 metres spot height values on the map of Port Adelaide gives a proposed new coastline for the Adelaide area. Most high tides at Port Adelaide are greater than 1.0 metre above the mean sea level so, at most high tides under this scenario, the sea level will be higher, with wave heights further above this level. Under extreme conditions with a repeat of the 1981 storm surge and a sea level rise of 1.0 metre and a high tide of 2.8 metres the sea level could peak at 5.2 metres with wave heights over and above that. The difference between tide heights and mean sea level is about 1.4 metres so the effective height of the extreme high tide plus storm surge plus sea level is about 3.8 metres above the current mean sea level.

West lakes and Port Adelaide are under water. The power station at Torrens Island is under serious threat as is the sewerage works at Bolivar. The Salt Works have disappeared.

Erosion will be taking place all along the Beach Front due to the extremely high tide and wave action. If the erosion is prolonged and unchecked Lefevre Peninsula may become Lefevre Island.

Remember also that the risk also extends to all our coasts. In all probability Port Pirie and Port Augusta will have major flooding and most of our coastal towns will be at risk.

(ii) River Murray

The height of the barrages at the Murray Mouth is 1.17 metres. High tides at present exceed 1.2 metres several times a year so that sea water already flows over the top of the barrages into the lakes at these times. A metre rise in sea level is likely to render these barrages ineffective for most of the time and therefore is likely to change the out-flow pattern in the river and affect the river levels as far upstream as Murray Bridge. The increased salinity could penetrate upstream also, with Adelaide's water supply at risk and it would destroy the Lower Murray and Murray Lakes irrigation areas.

There are opposing results of the Greenhouse Effect here with the increase in rainfall and change in seasonal distribution and the change in alpine snowline

changing the flow pattern of the river and the sealevel rise changing the outflow of the river. The likely result of these effects is the rise in water level in the lower reaches of the river which may put the flood plain irrigation areas at risk.

(b) Another Consequence of the Sealevel Rise?

There is also a more insidious problem than just a sealevel rise. Salt water may infiltrate into many coastal aquifers presently relied upon for irrigation. On the North Adelaide plains irrigation heavily depends on bore water with the result that some aquifers are depleted. There are already some restrictions on pumping in this area. An increase in sea level will increase the hydrostatic pressure on these aquifers and may lead to an increase in salinity in the ground water with perhaps disastrous results to the South Australian salad bowl.

CONCLUSION

The climate is changing. In the short term the major cause is the increasing concentration of CO_2 and other greenhouse gases.

The consequences for South Australia are changes in rainfall patterns which could affect agriculture and the native flora and fauna and a rise in sea level which will affect the South Australian coastline. The River Murray will be affected by both rainfall and sea level changes.

The changes may be controlled by reducing the CO_2 levels in the atmosphere but it will take about 25 years for climatic conditions to stabilise. If measures aren't taken to control the greenhouse gases then global temperature will continue to rise with melting of the west Antarctic ice sheet and a subsequent disastrous rise in the sea level of at least 5 to 7 metres over the next few centuries or so.

ACKNOWLEDGEMENTS

A.B. Pittock of the CSIRO Divison of Atmospheric Research in Victoria has done a lot of work on the Greenhouse Gases and their effects on Global Climate and I have used his work extensively in preparing this paper.

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THE ROLE OF BACTERIA IN ICE NUCLEATION

MARTIN CROWE

ABSTRACT

Recent work shows that some bacteria act as ice nuclei and are dispersed widely in the atmosphere. Some opportunities for related research in meteorology are mentioned, particularly the possibility of predicting drought-breaking rains by monitoring the atmospheric population of ice nucleation active (INA) bacteria.

INTRODUCTION

Studies in bacteriology and plant pathology have demonstrated that some bacteria act as ice nuclei. Soulage (1957) was the first to suggest that bacteria have an ice-nucleation facility and investigations into frost damage on plants (e.g. Lindow et. al (1982)) have provided strong evidence for this.

Bacteria associated with soil and plants have been detected in the atmosphere (Gregory (1973), Lindow (1982)) and their presence may be significant in the formation of precipitation. The fact that long, dry spells appear to cause marked reductions in the population of epiphytic bacteria promotes the view that drought is prolonged by a scarcity of ice nucleation active (INA) bacteria.

THE INA BACTERIA

Bacterial studies have revealed ice-nucleating properties in Pseudomonas syringae (Vali at al (1976)), Pseudomonas fluorescens (Maki and Willoughby (1978)) and Erwinia herbicola (Lindow et al (1978)). Examples of all three species have shown ice-nucleation activity at temperatures greater than -2°C.

Erwinia stewartii (Wallin et al (1979)), Pseudomonas viridiflava (Paulin and Luisetti (1978)) and Xanthomonas campestris p.v. translucens (Orser et al (1985)) also exhibit ice nucleation ability, but at lower temperatures.

Pseudomonas syringae, Pseudomonas fluorescens and Erwinia herbicola are in the form of rods 1.5 to 3.0 microns long, with flagella at the ends. All three are plant epiphytes but P. fluorescens is also associated with soil and water.

(Krieg (1984), Palleroni 1981).

The centre of ice-nucleation appears to be protein in the outer cell membrane of the bacterium (Wolber et al (1986), Lindow (1983)) which can retain its form after the death of the bacterium: hence both live and dead bacteria, or even fragments, act as ice nuclei. Maki and Willoughby (1978) disrupted populations of INA bacteria using sonic vibrations, then separated the soluble and insoluble components by centrifugation. They found the ice nucleation activity to be strongly concentrated in the sediment, with activity much reduced in the supernatent fluid, and concluded that the nucleation site was a part of the non-soluble cell walls.

Not all cells in a population of bacteria known to have ice nucleation ability are active at the same time. Some dependence on temperatures and growth environment has been found. (Lindow (1983)).

It is possible that the ice-nucleation faculty is part of a natural selection process in the evolution of these microbes. If they can cause frost injury to plants, the consequent ruptures provide access to more food (Lindow (1982)).

Vali (1968) determined that a large proportion of ice nuclei in his samples were smaller than 0.01 microns in diameter, which is about one hundredth the size of an INA bacterium. However, Phelps et al (1986) show that Erwinia herbicola grow and shed vesicles which act as ice nuclei, and the sizes of these particles are very close to Vali's 0.01 microns. Maki and Willoughby (1978), among others, mention the production of ice nuclei by bacteria. It appears that bacteria-derived nuclei may be considerably more significant in ice nucleation than the bacteria themselves.

BACTERIA AS ATMOSPHERIC AEROSOLS

Measurements show significant numbers of plant-based INA bacteria in the atmosphere, and they have been detected in areas remote from the plant source (Lindow (1982)).

Little of the research involving measurements of bacteria in the atmosphere concerns INA bacteria specifically, but it is reasonable to suppose that the means by which bacteria in general are transported also apply to the INA types.

Gregory (1973) gives details of several early measurements of airborne organisms including a set by Pady and Kelly (1954) which showed bacteria and fungal spores at an altitude of about 3000 metres all the way across the Atlantic Ocean from Canada to England. The bacteria count was very low at times but there was no gradual decrease with distance from land. They found that in W/NW winds over the North Atlantic there was a very low count of organisms, but high concentrations were carried in some tropical air masses with trajectories over agricultural lands.

It is thought that the airborne bacteria are separated from soil and plant surfaces by cultivation (Gregory (1973)), rainsplash and wind action (Lindow (1982)). Kuan (1986) derived counts of Xanthomonas campestris pv. campestris, in air over vegetation known to be infected with this bacterium, which ranged from 13.68 m^{-3} during rain to 0.84 m^{-3} in a dry period. The settling rate of these small particles is slow, allowing diffusion through the lower layers of the atmosphere by eddy turbulence and lifting to higher levels by processes such as convection.

There is strong evidence of higher concentrations of airborne microbes above temperature inversions, and Gregory (1973) mentions the possibility of the atmosphere itself being the normal habitat for some species of bacteria.

The role of natural selection in the evolution of INA bacteria, mentioned above could be extended to the spread of soil- and plant-based bacteria. These organisms become airborne and travel, but must leave the comparatively hostile upper air environment, where many species are known to be sensitive to desiccation and ultra-violet radiation. Natural sedimentation is slow, capture by raindrops is unreliable, but the ability to be instrumental in the formation of hydrometeors provides an efficient means of regaining the preferred habitat. Hence the individuals with ice nucleation ability survive. (Lindow (1982)).

QUESTIONS ARISING

Now that it has been established beyond reasonable doubt that some plant-based (and at least one strain of soil-based) bacteria act as ice nuclei and are widely dispersed through the atmosphere, a need for further research becomes apparent. The importance of INA bacteria in the formation of precipitation is unknown but may be significant. For example, Bigg [in Bell (1985)] suggests

that clay particles previously thought to act as ice nuclei may do so only because they carry INA bacteria.

Bacteriologists have determined that the populations of bacteria vary with the season of the year, weather, and stage in the growth cycle of the hose plants (Lindow (1983). Little work appears to have been done on the escape of these organisms from plants into the atmosphere, or on patterns of INA bacteria distributions in the atmosphere in general and in weather systems in detail. For example, when a weather system produces rain, what is the role of locally released INA bacteria compared to that of the population carried by the system itself? Are there some types of precipitation or classes of weather system in which bacteria play a major role and others in which their part is relatively insignificant? Would knowledge of the three-dimensional INA bacteria distribution field around a front, or ahead of a moist influx of air, assist in forecasting the amount of rainfall that weather system will produce? And if so, would the effort needed to obtain such a field be sufficiently rewarded by the increased forecast accuracy?

One of the more intriguing ramifications is the role played by the lack of bacteria during a drought. It seems that a weather system which would normally produce an appreciable amount of precipitation will often yield very little over an area suffering a prolonged dry spell. Lindow (1983) points out that populations of INA bacteria on plants decreased in hot, dry conditions, so it is to be expected that after a period of drought, a bacteria count would be very low. An increase in bacterium numbers may be needed to produce rains. Local growth before rain is unlikely so an influx of bacteria-laden air from a suitable source appears to be necessary. The question is complicated by the fact that although hot, dry weather kills bacteria, it does not necessarily kill the protein in the cell membrane, which is the nucleating centre, and dead bacteria with intact cell walls may remain active in ice nucleation (Lindow 1983).

DETECTING AND COUNTING INA BACTERIA

Research into the significance of bacteria in the production of precipitation requires detection and enumeration of the organisms. Usual techniques for identifying and counting bacteria involve culturing and staining, but the ice-nucleating quality of the relevant bacteria, and the fact that they are active as nuclei at temperatures between -1°C and -5°C, provide a basis for easier

measurement. The method used by Bigg et al. (1963) involving Millipore filters, could be adapted using controlled temperatures in the -1°C to -5°C range. The essence of the procedure is to grow ice crystals around the ice nuclei so they are big enough to be seen and counted. In the appropriate temperature range, only bacteria or bacteria-derived particles will be active as ice nuclei.[1]

Pady and Kelly (1954) describe the methods and equipment they used in an aeroplane over the North Atlantic Ocean. Kuan et al. (1986) used an Andersen viable particle sampler (see Andersen (1958)) and Langer (1973) gives an account of a continuously operating ice nucleus counter, tested in an aircraft. Membrane filter techniques are described in detail by Mulvany (1969).

CONCLUSION

The fact that INA bacteria exist in the atmosphere offers a possible means of improving precipitation forecasting. A considerable amount of research must be done in measuring the INA bacteria content of the air both near the ground and at icing levels before an assessment can be made as to the worth of such information in real-time forecasting, but the possibilities are worth exploring.

[1] The crystalline forms of some organic compounds such as terpenes (Rosinski and Parungo (1966), Went (1966)) act as ice nuclei at temperatures higher than -5°C but the natural occurrence of these is thought to be rare (Lindow,1983)

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GLOSSARY (for the use with this paper and its references)

Agar: (or agar-agar) A dried mucilaginous substance with marked gel-forming properties, obtained from certain oriental seaweeds, free from nitrogen, a carbohydrate derivative used as a substitute for size, a laxative, as an ingredient in certian foodstuffs and in the preparation of certain media for the cultivation of many kinds of bacteria and moulds.

Amino Acids: Aminoalkanoic acids: A group of organic acids in which a hydrogen atom of the hydrocarbon (alkyl) radical is exchanged for the amino group: Some 24 2-amino acids (i.e. having the amino group attached to the carbon next to the carboxyl group) occur in proteins.

Amino group: The grouping where R may be hydrogen, or organic radicals.

Antibiosis: A state of mutual antagonism.

Autoclave: A thick-walled steel vessel for carrying out chemical reactions under pressure and at high temperatures.

Autotrophic: Able to build up food materials from simple substances.

Bacteria: A large group of unicellular or multi-cellular organisms, lacing chlorophyll, with a single nucleus, multiplying rapidly by simple fission, some species developing a highly resistant resting ("spore") phase; some species also reproduce sexually, and some are motile. In shape spherical, rodlike, spiral or filamentous, they occur in air, water, soil, rotting organic material, animals and plants. Saprophytic forms are more numerous than parasites but the latter include both animal and plant pathogens. A few species are autotrophic.

Brassica: A genus of Cruciferae (Brassicaceae) which includes cabbage, radish, wallflower and many common wildflowers.

Commensalism: An external, mutually beneficial partnership between two organisms.

Cryogenics: Term applied to low-temperature substances and apparatus.

Epipabs: Epiphytic phytopathogenic bacteria.

Eubacteriales: One of the two main orders of true bacteria, distinguished from the Pseudomonadales by the peritrichous flagella of the motile members. Spherical or rod-shaped cells, having no photosynthetic pigments; not acid fast; readily stained by aniline dyes.

Flagellum: A thread-like extension of the protoplasm of a cell, or a Protozoan, which is capable of carrying out lashing movements.

Gram-positive: Said of bacteria which stain when treated with a basic dye of the tri-phenyl-methane group, followed by mordanting with iodine and washing in acetone or ethyl alcohol. Bacteria which do not stain are termed Gram-negative.

Holophytic: Able to manufacture food from the simplest beginnings by photosynthesis, and neither parasitic nor saprophytic.

Holozoic: Devouring other organisms.

Isomerism: Two chemical substances having the same formula but different arrangement of atoms and, therefore, different properties.

Ketogenic: Capable of producing ketone bodies.

Ketones: Compounds containing the carbonyl group - CO - in the molecule attached to two hydrocarbon radicals. General formula $R\text{-}CO\text{-}R^1$: the simplest ketone is acetone.

Lysis: Decomposition or splitting of cells or molecules (as in hydrolysis). Destruction of cells or tissues by various pathological processes.

Metaldehyde: Meta-aldehyde $(CH_3\ CHO)_4$: long, glistening needles which sublime at 115°C with partial decomposition into ethanol. Acetaldehyde is polymerised to metaldehyde by the action of acids at temperatures below 0°C.

Mordanting: Adding to a silver image or replacing a silver image by a substance having the requisite affinity for a specific dye, which silver, in itself, has not.

Necrosis: Death of a cell or a group of cells while still part of the living body. adj. necrotic.

Nucleus: A minute solid particle suspended in the atmosphere:

$r < 0.2$ microns	Aitken nuclei
0.2 microns $< r <$ 1.0 microns	Large nuclei
$r > 1$ micron	Giant nuclei

Oxidase: One of a group of enzymes occurring in plant and animal cells and promoting oxidation.

Pathogen: A parasite producing damage in its host. Any disease-producing organism or substance. adj. pathogenic.

Pathovar: An infrasubspecific rank applying to strains having pathogenic properties for certain hosts. (Pathogenic variant?)

Peritrichous: (of bacteria) with flagella distributed over the whole surface of the cell.

Phage: Abbreviation for bacteriophage - general term for viruses which affect bacteria.

Phenazine: A heterocyclic compound which can be considered as anthracene in which two CH groups have been replaced by two N atoms. It has the formula: $C_{12}\ N_2\ H_{12}$
It crystallizes in yellow needles, melting point 171°C and can be readily sublimed.

Phenotype: The observable characteristics of an organism produced by the interaction of genes and environment. adj. phenotypic.

Phylogenetic series: The complete range of organisms, extant and extinct, which shows the evolution of the higher forms from the lower forms. [Phylo - from the Greek for race].

Phyto-pathogenic: Producing disease in plants.

Phyto-pathology: The study of disease in plants, especially in relation to parasites.

Prokaryon: The nucleus of a blue-green alga or of a bacterium.

Proteins: Complex nitrogenous substances composed mainly of amino acid residues joined by the "peptide linkage" which is formed when water is eliminated from the carboxyl group of one amino acid molecule and from the amino group of another. Molecular weights tend to be approximately multiples of 17,600. Most form colloidal solutions in water or dilute salt solutions.

Protoplasm: The material basis of all living matter, a greyish, semitransparent, semifluid substance of complex chemical composition, within which physical, chemical and electrical changes are constantly taking place.

Protozoa: A sub-kingdom and phylum of animals. Small animals of varying shape and complex microstructure, unicellular or acellular. Nutrition holophytic, holozoic, saprophytic. Reproduction by fission or conjugation, locomotion by cilia, flagella or pseudopodia, free-living or parasitic.

Pseudo-monadales: One of the two main orders of true bacteria, distinguished by the polar flagella of the motile forms. Gram-negative. Spiral, spherical or rod-shaped cells.

Saprophyte: Any bacterium which breaks up dead animal and vegetable matter

and does not produce disease in the animal or plant it inhabits. Generally, an organism which obtains its food from dead organic material.

Spore: (In Protozoa) A minute body formed by multiple fission: More strictly, a seedlike stage in the life-cycle of Protozoa arising as a result of sporulation, and contained in a tough, resistant envelope.

Steroids: Compounds containing the perhydrocyclopenteno-phenanthrane nucleus. They include sterols, bile acids, sex hormones, adreno-cortical hormones, cardiac glycosides, sapogenins and some alkaloids. (Cholosterol is a sterol).

Terpene: (a) Any of a class of isomeric hydrocarbons $C_{10}H_{16}$.

(b) Any of a class of hydrocarbons $(C_5H_8)n$, most of which occur in plants.

WEATHER CONDITIONS DURING BRITISH ATOMIC BOMB TESTS IN AUSTRALIA, 1952-1957

ADRIAN GORDON

This is an edited version of the full text of a talk given to the Society on 18 February, 1987.

INTRODUCTION

There were five separate periods for the major atomic bomb trials in Australia during which 12 bombs were exploded in three localities within the period October 1952 - October 1957 inclusive. Table 1 shows the details of the trials, listing the code name of each operation, together with the date of firing, the place of firing, the type of burst and the yield. For comparison of yields the bomb, code named Bravo, believed to be the most powerful of all the American H bombs, has been estimated at 15 megatons. Figure 1 shows a map of Australia with the three sites of the major series of tests labelled.

In this report a study is made of the weather conditions associated with each of the 12 tests. Some critical comment is offered concerning the efficacy of the various operations from a meteorological point of view.

BRITISH NUCLEAR TESTS IN AUSTRALIA

Operation	Date	Place	Type	Yield
Operation Hurricane	3 October 1952	Monte Bello Islands	Ocean burst (ship)	25 kilotons
Operation Totem				
Totem One	15 October 1953	Emu Field	Tower	10 kilotons
Totem Two	27 October 1953	Emu Field	Tower	8 kilotons
Operation Mosaic				
Mosaic G1	16 May 1956	Monte Bello Islands	Tower	15 kilotons
Mosaic G2	19 June 1956	Monte Bello Islands	Tower	60 kilotons
Operation Buffalo				
One Tree	27 September 1956	Maralinga	Tower	15 kilotons
Marcoo	4 October 1956	Maralinga	Ground burst	1.5 kilotons
Kite	11 October 1956	Maralinga	Aircraft-drop	3 kilotons
Breakaway	22 October 1956	Maralinga	Tower	10 kilotons
Operation Antler				
Tadje	14 September 1957	Maralinga	Tower	1 kiloton
Biak	25 September 1957	Maralinga	Tower	6 kilotons
Taranaki	9 October 1957	Maralinga	Balloon-suspended	25 kilotons

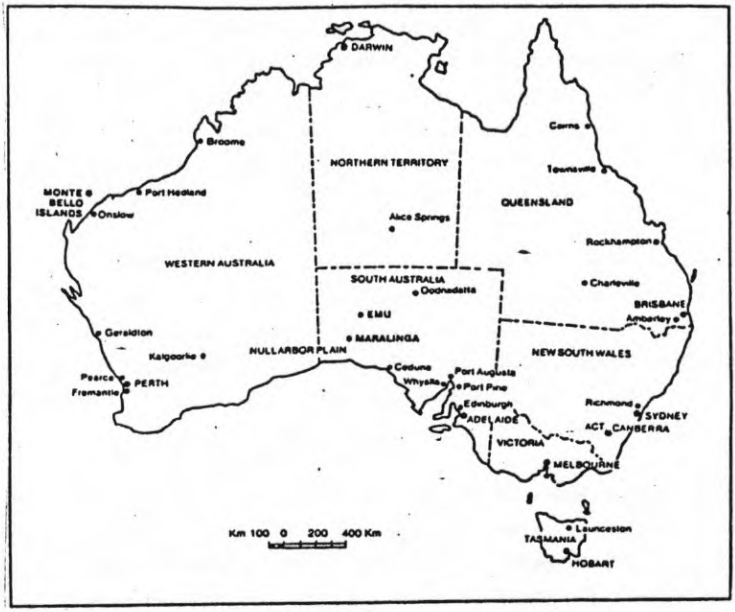
One kiloton is equal to 1000 tons of conventional explosive, TNT.
One megaton is equal to one million tons of TNT.

Table 1 Details of the British Nuclear Tests in Australia

THE MONTE BELLO AFFAIR

The first bomb trial was code named Hurricane. It was exploded at 8a.m. local time on 3 October 1952 in the hold of a disused naval vessel anchored within the Monte Bello group of islands off the coast of Western Australia.

Figure 1 Map of Australia Showing Test Sites



Why was Monte Bello chosen? Why was the month of October selected?

On 26 March 1951 British Prime Minister Attlee informed Prime Minister Menzies of Australia, that it would be possible to conduct atomic test trials there, and further, that they could only take place in the month of October for climatic reasons, namely that the prevailing wind conditions at the Monte Bellos were such that October was the only month for which there was a reasonable chance of winds that did not blow towards the mainland.

It was hoped that any radioactive fallout would pass away to sea, but this may only have been a faint hope as information gleaned by the Royal Commission into the British Nuclear Tests in Australia (1985) indicated that the planners of the test were well aware that fallout would travel in an easterly direction and that it could be monitored not only over the mainland, but also further to the east in Fiji and possibly New Zealand.

In fact as early as July 1951 a report was produced which concluded that if the wind came from directions between west and northeast, through north, the contamination on the mainland could exceed the levels laid down by the Medical Research Council for civilian populations.

The author did a study of the mean vector wind and wind components at Port Hedland, the nearest station for which detailed records of upper air data are published for the period 1957-1975. Port Hedland is 160 miles roughly north-east of the Monte Bellos, but for the purposes of this study could be considered to have a similar broad scale climate. For the time of the tests, the statistics of this period could similarly be considered as representative.

The results show a well established upper westerly wind regime which occurs from April through December. The westerly wind in October is strong and in fact extends down to 850 mb, a lower level than that of any other month. Furthermore, the northerly component of the wind in October is stronger at 700 mb than in any other month, and it was a northerly direction combined with a westerly direction, that was designated to be wholly unfavourable for firing.

A parameter which was widely used at that time was the 'effective' wind. This was simply the mean vector wind computed from any given upper level down to the surface as if it had been carried along by this effective wind. On the basis of these 'effective' winds computed from the Port Hedland data it would have been incredible for a statement from the British Prime Minister to say that "the prevailing wind conditions at the Monte Bellos were such that October was the only month for which there was reasonable chance of winds that did not blow towards the mainland". In fact it appears that October has an overall deeper layer with winds in the forbidden sector than has any other month.

January-March inclusive have effective winds which are easterly from all levels. Possibly these months were excluded because of the possibility of occurrence

of tropical cyclones, but this eventuality is not mentioned in any of the meteorological references to the choice of October.

Prior to the firing of the weapon more precise conditions were laid down for the meteorologists to follow. These were:-

(a) the mean wind from the surface up to all levels must not have a direction lying within the sector 300 degrees to 060 degrees through north.

(b) The mean wind direction must be south of 260 degrees
  (i) for the layer from the surface to 5000 feet
  (ii) for the layers above 25000 feet

(c) a direction of mean wind north of 260 degrees can be accepted if
  (i) the conditions in (a) are not violated
  (ii) the layer in question is not more than 5000 feet thick

The first condition (a) on the wind was to protect the task force on the islands. Conditions (b) and (c) limited the level of fallout on the mainland. In effect these more precise conditions were not greatly different from the original. The forbidden sector was widened from 045° to 060° and conditions (b) and (c) were introduced.

How well do the mean climatological winds meet the required winds as interpolated by the meteorologists? It appears the condition (a) is met in January, February, March and July. However, the fulfillment of condition b (ii) is doubtful. At 300 mb the mean monthly wind is south of 260 degrees in January and March but at 200 mb it is north of 260° in all months.

The actual winds at the time of the Hurricane explosion did fall within the limits required. However, there was evidence that winds above 12000 feet were westerly. Although the cloud was reported to have risen to only 11600 feet some material no doubt reached higher levels. The Royal Commission Report concludes:-

> "There was fallout on the mainland and following Hurricane (the operation code name), although most of the activity fell in the sea to the north west as was intended".

In retrospect it should be noted that the predicted height of the atomic cloud

was more than double the actual height. (In later explosions the height of the cloud top was often seriously underestimated). If there was fallout when the cloud only reached 11600 feet there would have been a far greater concentration over the mainland if it had risen to 25000 as predicted.

The conclusion of this case study must be to confirm that there was no meteorological basis at all for selecting October as the only or best month to fire the nuclear explosion in the Monte Bello Islands. It seems evident the choice of October was a political ploy in which meteorologists were used. It is mentioned in the documents that October was the earliest date by which the prototype of the British weapon would be ready. It would seem that the choice of October as the only suitable month for the test was made to ensure that the bomb would be ready by then and fired as soon as it was ready in order to demonstrate British progress and strength to both the Americans and the Soviets. ". . . that for climatic reasons this can only be done in October. My colleagues and I have decided that to wait any longer for the Americans would mean subjecting our plans to an intolerable delay. If, therefore, your Government would agree, we would like to go ahead now with preparations for a test at the Monte Bello Islands in October 1952, which is the earliest date by which a prototype will be ready" (British Prime Minister Attlee to Australian Prime Minister Menzies, 29 March 1951).

TOTEMS AT EMU

Of all the British atomic tests conducted in Australia the two Totem explosions at Emu, near Maralinga in South Australia probably attracted the most attention. It was, in fact, because of the allegations of the occurrence of a "Black mist" by Aboriginal and non-Aboriginal people, that these tests, and particularly the first of the two explosions, fell within the media spotlight. Most of the people affected were at the settlement of Wallatinna, 173 km north-east of Emu. It was alleged that various symptons of illness occurred, including vomiting, diarrhoea, skin disorders, blindness, and deaths.

After the Monte Bello trials in October 1952 rapid progress in nuclear research led to an urgent need for further tests. The race within the United States and the U.S.S.R. continued at great pace and it had become essential, even before Monte Bello in October 1952, to search for new sites at which land based experiments could be mounted. The region chosen was in the great desert of South Australia, an isolated spot at about 28.5°S, 132.3°E. In this case the month of October 1953 had been chosen in December 1952 on grounds of expediency.

An approximation to the upper wind regime in the Maralinga locality can be found from a study of the statistics for Forrest, a meteorological station about 300 miles southwest of Emu. This reveals that there are strong westerlies in the middle atmosphere, particularly in Spring, Autumn and Winter. In October a westerly component extends from 900 mb to 70 mb. In this case the selection of a suitable month had to include climatic conditions which allowed radioactive fallout to drift somewhere over the continent, since the site was located some 200 miles from the ocean.

Once again specific firing conditions were laid down. They were,

(a) the mean wind from surface to any level below 10000 feet does not lie between 330° to 130° through north.

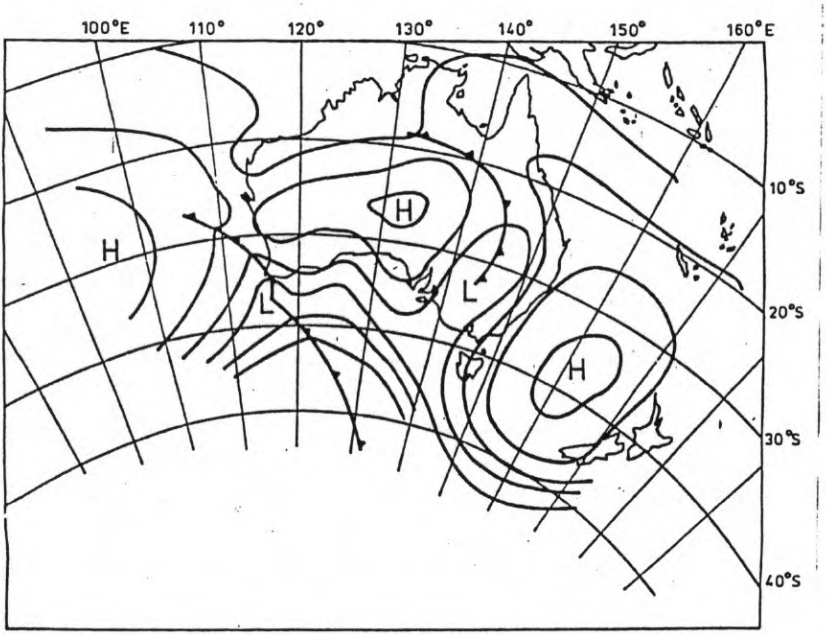
(b) it is forecast that no rain will fall within 12 hours nearer than 200 miles downwind.

These conditions ignored certain conclusions that low wind shear could result in excessive contamination. The question of wind shear was not included in the firing criteria.

Totem 1 was fired at 0700 CST on 15 October, 1953. The explosion cloud reached a maximum height of 15000 ft. An aerological ascent for 0300 CST showed the upper air to be very stable. Considering the time of year it would be reasonable to suppose a maximum temperature for the day of 20°C. It was 8.6°C at firing time. Then the convective boundary layer in which mixing of fallout would occur would have extended to about 5000 feet. Fallout material might well have recycled within this convection layer for some hours before settling to the ground. Green (1986) suggests a mechanism which he calls "convection levitation" which explains the concentration of small particles in preferred localities, particularly in the upper part of an unstable layer. This mechanism suggests that dispersal substances are likely eventually to come down in dollops, not be evenly distributed over wide areas.

A study of the effective or mean vector winds from the surface to various levels up to 15000 feet at approximate firing time showed that condition (a) was met. Also a glance at the mean sea level synoptic chart for the area at approximate firing time (Figure 2) suggests the approach of an anticyclone from the west. Consequently, no rain would have been expected downwind for some time, satisfying condition (b).

Figure 2. M.s.l. Synoptic chart at approximate firing time for Totem 1.



The Royal Commission's conclusion was that Totem 1 should not have been fired because the absence of any appreciable wind shear would permit dangerously high radioactive fallout within the relatively narrow path of the atomic dust cloud. Although the danger of low wind shear had been realized and documented in a pre-trial study, this factor appeared to have been forgotten during the actual operation.

A hodograph (not reproduced here) of the effective winds for Totem 1 as portrayed on a polar coordinate diagram showed that the swathe of contaminated cloud embraced the villages of Wallatinna and Welbourne, the inhabitants of which reported a "black mist". Wallatinna is situated at 173 km from Emu on a bearing of 036 degrees which means that a mean vector wind of 216° would have passed over the site. It is evident that the wind in the upper part of the convective boundary layer actually blew coincident with Wallatinna. No wonder the Aboriginal inhabitants reported a "black mist" bearing down on them. There

would, of course, have been a cross-wind spread estimated at the time for Totem 1 to be 24 km at the distance of Wallatinna.

After leaving Wallatinna the cloud was tracked by aircraft northeast across the continent, eventually reaching the Pacific Ocean over central Queensland.

TOTEM 2

Totem 2 was fired at 0700 CST on 27 October 1953 with an approximate yield of 8 kt. The firing criteria were the same as for Totem 1 with the added proviso that "firing conditions for Totem 2, if necessary, can be slightly less stringent because we do not this time have to preserve a clean firing site for an immediately following trial" (Penney, July 1952).

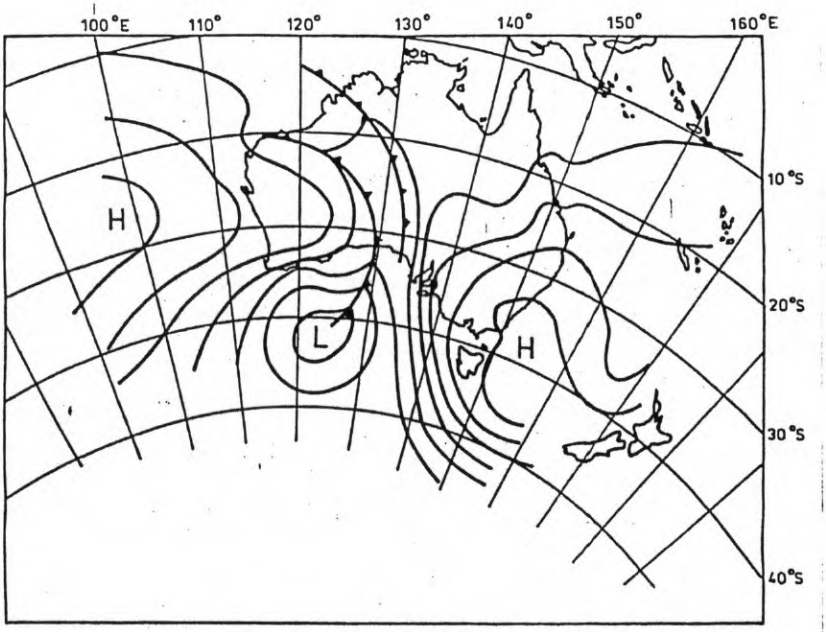
The weather conditions prevailing for Totem 2 were quite different than for Totem 1. In effect it is doubtful if either conditions (a) or (b) were met. Certainly the effective wind from the surface to all levels up to 10000 feet fell within the forbidden sector. The Commission, however, concluded that the weather conditions at the time of firing Totem 2 satisfied the criteria for firing. Obviously, condition (a) must have been obviated by the rider above in respect of Totem 2, but there seems to be some mystery about the decision.

Instead of a little wind shear there was large wind shear. Instead of a basically stable atmosphere the whole atmosphere was conditionally unstable to 300 mb (30000 feet). Instead of light south westerlies there were strong gusty northerlies at the surface. Instead of a further outlook of fine anticyclonic weather there was the possibility of a cool change accompanied by a frontal passage and a chance of thunderstorms.

A hodograph of the effective winds for Totem 2 at approximate firing time showed a swathe of 95° to which an additional total angle of 10° should be added for cross-wind dispersion. The bomb cloud was first estimated to have risen to 28000 feet. Subsequently the estimate was revised to only 20000 feet. This would, if correct, reduce the swathe to 88° including cross-wind dispersion.

The surface synoptic chart reasonably near firing time is shown in Figure 3. It is noted that a weak cold front is almsot directly over the station at the time of firing, followed by a stronger cold front behind which there is much cooler air originating from the Southern Ocean.

Figure 3. M.s.l. synoptic chart at approximate firing time of Totem 2, 27 October 1953



The extreme instability indicated in the aerological ascent at Emu at the approximate firing time could have resulted in unforseen dangers. Assuming a probable maximum temperature of 37°C which could have occurred with a strong north wind and early morning temperature of 24°C at 3000 feet, the surface layer could have ascended to 300 mb causing a thunderstorm. The condensation level was at about 650 mb or 11000 feet. In fact, the surface convergence associated with the surface trough would have assisted vertical motion. Rain could have occurred, or even a microburst, which would have brought everything down with great speed.

In addition, the presence of the two cold fronts approaching from the west could have resulted in a reversal of the fallout direction such that it returned over the heads of the encamped station personnel. The fact that the criteria for firing were met as laid down previously does not mitigate the fact that changes could have occurred very soon after firing which would contravene such criteria.

There is some evidence more conducive to a mystery movie thriller than a highly organized para-military operation.

Tame and Robotham (1982) claimed that "....immediately after the bomb had been dropped from its tower and exploded, the fallout cloud began drifting, as in Totem 1, in a northeasterly direction, away from Emu village and its living quarters. Then, to the dismay of the watching scientists, wind shear took the cloud back on itself, heading it directly for their home base. It is not difficult to imagine the haste with which they packed and departed. Nor is it difficult to imagine the reluctance there would have been to own up to such an undignified flight. The questions of safety posed by such a confession would indeed have been difficult to answer".

Although the Report of the Royal Commission included the above extract the official conclusion was that there was no evidence to support allegations of an emergency evacuation after the Totem series.

Figure 4. Transposition of hodograph of effective winds on to map of Australia, showing width of area covered by possible fallout.

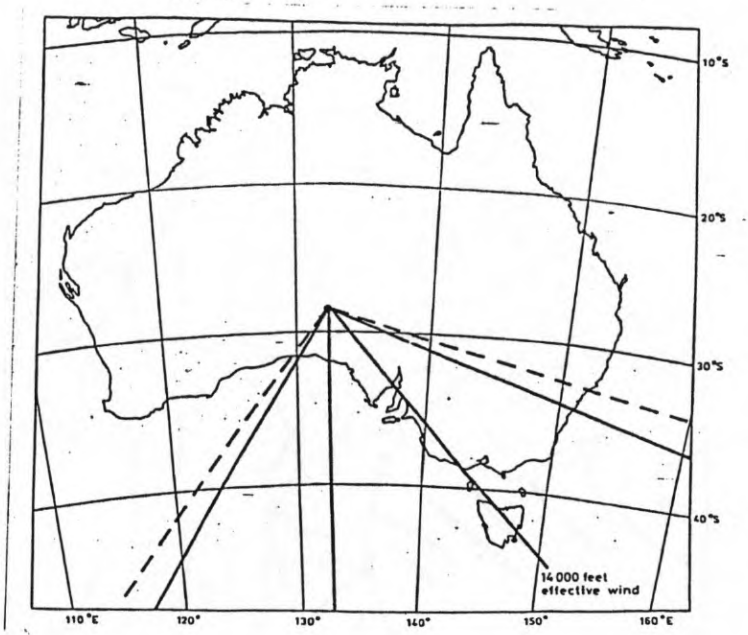


Figure 4 shows a transposition of the hodograph of effective winds from Figure 7 on to a map of Australia. The 14000 foot effective wind would reach Adelaide in just over 24 hours. Rain was recorded in Adelaide on 29 and 30 October. However, it is the practice of the Bureau to record the rainfall total for a given day as that rain which fell during the 24 hours preceding 9 a.m. on that day. Hence rain could have started to fall in Adelaide at 9 a.m. on the 28 October just about 24 hours after the firing of Totem 2. In fact records show that for the 24 hours ending at 9 a.m. on 28 October one or two points (1 point = 0.01 inch) had fallen in the Adelaide foothills with a maximum of 7 points at Stirling, near Mt. Lofty. For the 24 hours ending at 9 a.m. on 29 October records show general light rain over Adelaide with 11 points falling at Happy Valley Reservoir. Rain was heavier elsewhere with maxima over an inch at OOdlawirra in the Upper north agricultural belt and 70 points at Renmark.

Figures 5 and 6 show the m.s.l. synoptic charts for 3 p.m. local time on 28th and 29th October 1953, respectively, about 32 and 56 hours after the firing of Totem 2. The shaded area in figure 6 indicates the area over which rain fell during the preceding 24 hours.

Figure 5 M.s.l. synoptic chart for 3 p.m. local time on 28 October 1953

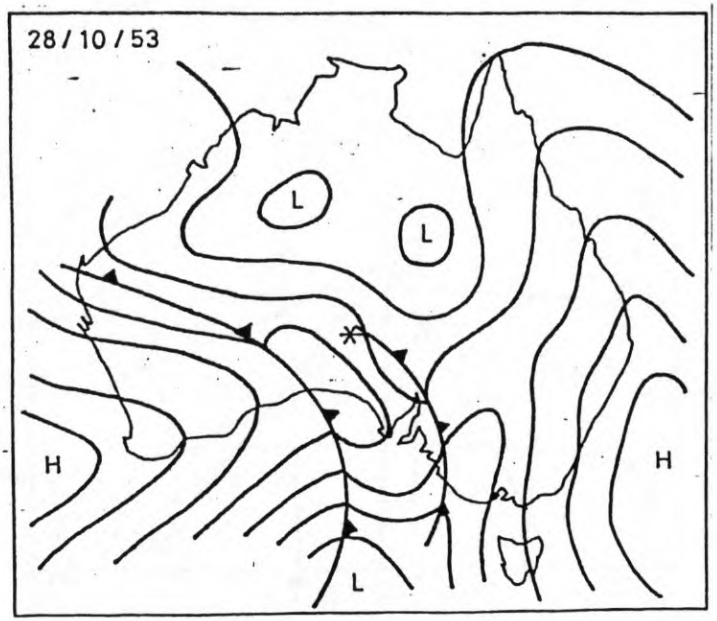
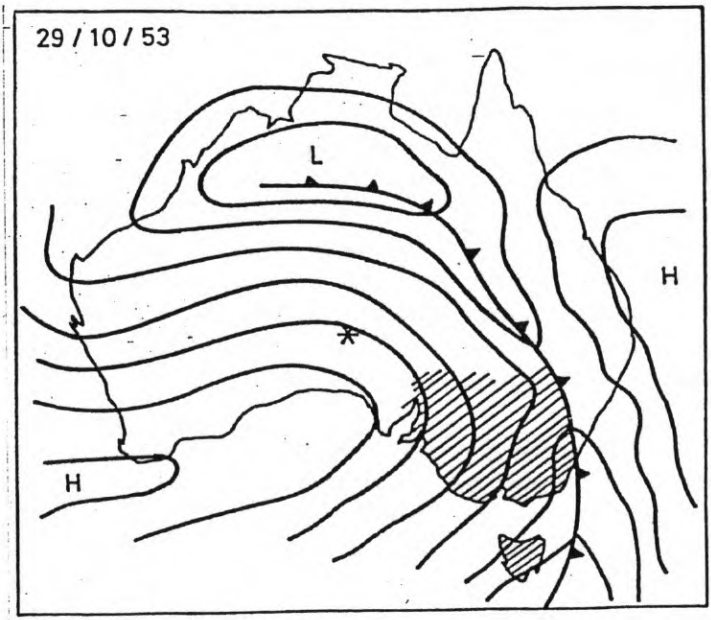


Figure 6. M.s.l. synoptic chart for 3 p.m. local time on 29 October 1953.



It is quite probable that there was radioactive washout over much of the area. Some of it would have flowed into Happy Valley and other reservoirs where the concentration would have increased because of the convergence of the runoff into a small reservoir area.

The Royal Commission Report does not contain stickypaper record maps of fallout as for subsequent trials so there does not appear to be any detailed record of what actually happened after Totem 2.

MONTE BELLO AGAIN — MOSAICS

After the totem explosions nuclear research turned towards the testing of a thermonuclear weapon. The distinction between an atom bomb and a thermonuclear bomb is that the energy of the former is derived from fission whereas that from the latter is derived from fusion. A fusion bomb requires intensely high temperatures to set it off. Such temperatures can only be produced by atomic explosions themselves.

Consequently the United Kingdom turned its attention towards the testing of devices which could act as triggers to the much more powerful hydrogen bomb. Once again, the Monte Bello Islands came into the limelight as a possible site for the next round of tests. But this time there appears to have been no mention of October as being the most favourable month climatically.

The Royal Commission Report stated that no advice appears to have been provided or asked for as to why tests were being planned in April, the month asked for by Prime Minister Eden in a message to Prime Minister Menzies on 17 May, 1955, when it had been considered previously that for "climatic reasons" the Monte Bellos were only suitable in the month of October. This time it was operationally necessary for the tests to be undertaken in May and June 1956. It seems clear in retrospect that in both Monte Bello trial periods, political expediency and a race against time for Britain to develop its potential nuclear weapon program as rapidly as possible, were the sole factors in determining the months in which the tests took place, not climate.

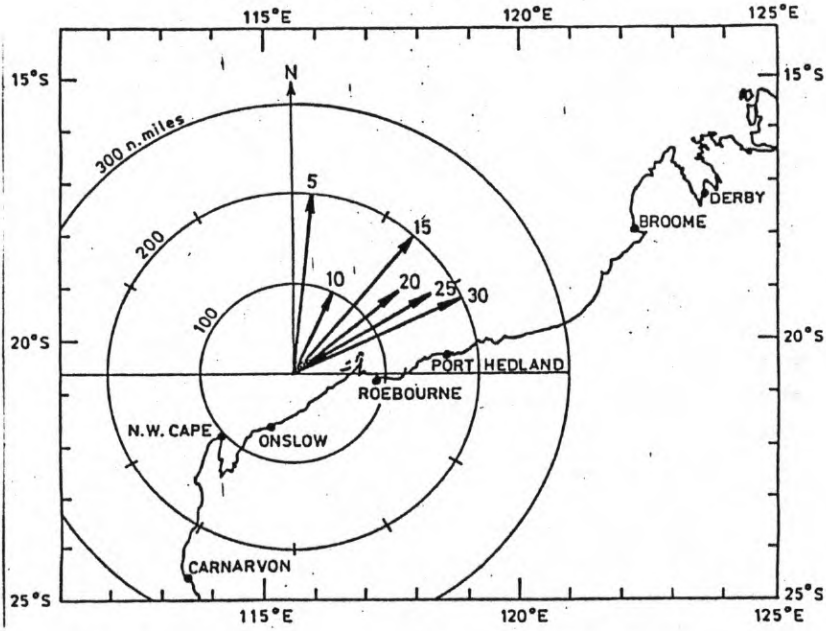
Studies have shown that the westerly component of the wind is stronger in May and June than in October and that it extends from 700 mb (about 10000 feet) upwards to the stratosphere. Westerly winds were clearly unfavourable because the fallout would be blown directly to the mainland. In only about one day in three months would the wind be suitable for firing. With such a rarity of favourable conditions the Royal Commission concluded that the Monte Bello Islands were not a suitable site for the tests.

The firing restriction for Mosaic was stated in simpler terms than for Hurricane. They were that meteorological conditions would be such as to ensure that there would be no fallout in the sector 050° through south to 250°. As the fallout would be in the sea there would be no need to place additonal restrictions on the speeds or directions of the winds at different altitudes. These restrictions excluded any effective wind between 230° and 070° through north.

Mosaic 1 was fired at 1150 hours local time on 16 May 1956. The top of the cloud reached 24000 feet. Figure 7 shows a hodograph of the forecast effective winds at the firing time. A 5° increase on each side of the total sweep has been added for crosswind dispersion. The wind structure just marginally meets the firing criterion for the estimated cloud height, which was underestimated by 6500 feet. The actual fallout extended right across Western Australia with greater intensities from the Monte Bellos inland to the Pilbara and inland

south of Broome. This is considerably different from that which would have been expected from the forecast winds. It is clear that firing took place under very marginal conditions, even on the basis of the forecast winds.

Figure 7. Hodograph of the effective winds as forecast at firing time for Mosaic 1.



Dwyer, Director of Meteorology, in a report dated 5 June 1956, was quite satisfied with the result and confirmed that the forecast held in almost every detail. He stated that after 36 hours from firing it was apparent that no danger had or could be incurred by the inhabitants or property on the mainland.

Various reasons were given to explain the fallout observed. Of these it was said that there was a change in the wind following the explosion. They weakened and blew from the north and west. Hence part of the cloud was blown first to the north and then back again to the south. Such a wind change should be associated with the passage of a warm upper ridge. However, there is little evidence from synoptic charts to show this.

The 500 mb chart at 1400 local time on 16 May 1956, about two hours after firing time shows a weak ridge to the west of the Western Australian coastline which may have moved eastwards, but this is speculative as there is little observational evidence. A simpler reason might be that the cloud reached some 6500 feet higher than had been expected and so fallout material reached levels where the westerly component of the wind was stronger. Also onshore northwesterly sea breezes might have occurred during the late afternoon along the whole coastal strip.

However one looks at it one must come to the conclusion reached by The Royal Commission - "... either way, somebody got it wrong".

The second bomb, Mosaic 2, was fired on 19 June 1956 and it was feared that no suitable day would occur in time. The first sign of suitable weather was not until 13 June. In this case 30% was added to the cloud height prediction as a margin of safety because of the error in the predicted Mosaic 1 height. On 18 June conditions appeared favourable and the firing sequence proceeded.

The predicted winds from the Monte Bello aerological ascent were both marginal and optimistic in meeting the firing criteria. Again the fallout pattern showed a marked concentration over the northwest, then right across the northern Australian land mass.

"... the fallout in the mainland following Mosaic 2 was again greater than expected and occurred at locations where no fallout had been predicted. The post-firing winds behaved similarly to those after Mosaic, i.e. they weakened and then began to blow from the south and east. An analysis of the trajectories of fallout particles showed that fallout at Port Hedland occurred 24 hours after the explosion and consisted of particles that originated from 20000 feet, in the region of the top of the stem and the bottom of the cloud. Fallout occurred at Derby 24 hours after the explosion of particles that originated at 30,000 feet in the main cloud".

It is hardly credible to believe that the winds changed in exactly the same way in both Mosaic explosions. Rather it is more likely that the wind regime nearer the mainland coast was different from that in the islands, perhaps because of the geographic effect of the mainland itself. Clearly, if the Port Hedland winds had been used instead of the Monte Bello winds, the predictions would have

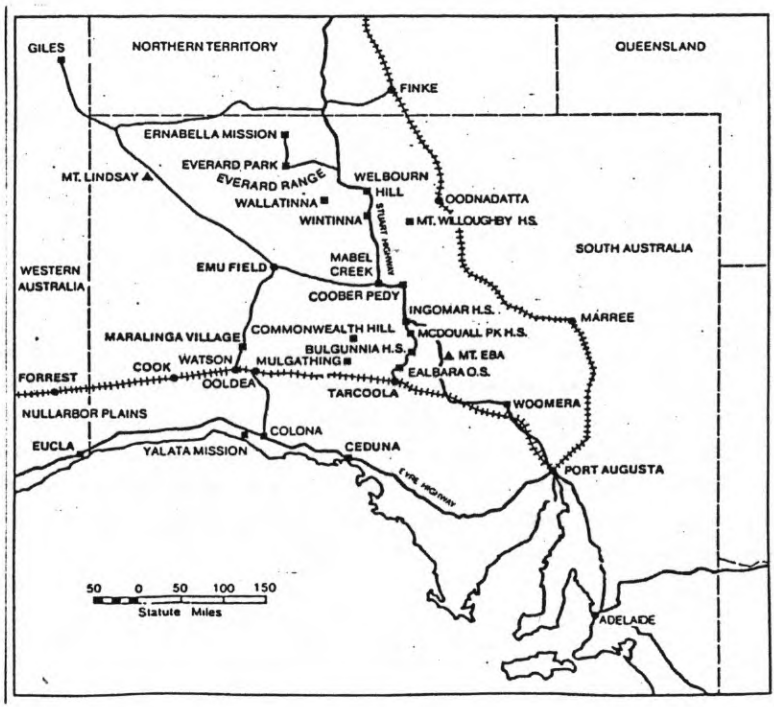
been much more accurate, and the firing of the bomb delayed. Claims which had been made that something had gone radically wrong with the test were certainly quite justified.

MARALINGA - ANTLERS AND BUFFALOES

After the high yield Mosaic 2 test in the Monte Bello Islands the total number of explosions was 5. There were 7 more to come before the conclusion of the program. These were all conducted on the new Maralinga range. There were two series of trials, Buffalo in September and October 1956, and Antler in September and October 1957. There were four detonations for the Buffalo series and three for the Antler series.

Figure 8 shows the location of Maralinga within the western half of South Australia.

Figure 8. Map of South Australia Showing Location of Maralinga



By this time technical and operational practices and procedures had improved considerably since the early trials. On the other hand public concern was becoming more outspoken. In 1958 this concern found its expression in a moratorium on all forms of atomic testing. Also, the actual meteorological firing criteria seemed to be much less precise than for the early trials. Firing criteria were based on the acceptable levels of fallout contamination. The wording was "no local contamination to occur south of Ground Zero and beyond one mile from Ground Zero. Medium range fallout, outside of a prescribed boundary line not to exceed level A. No precipitation within 500 miles of Ground Zero". Level A was defined as "that level which will not give rise to any observable effects on the body". This level was recommended as the highest acceptable dosage for aborigines and other population.

The specified meteorological conditions for the Buffalo and Antler trials appeared to be

(a) no low level wind direction with a northerly component;

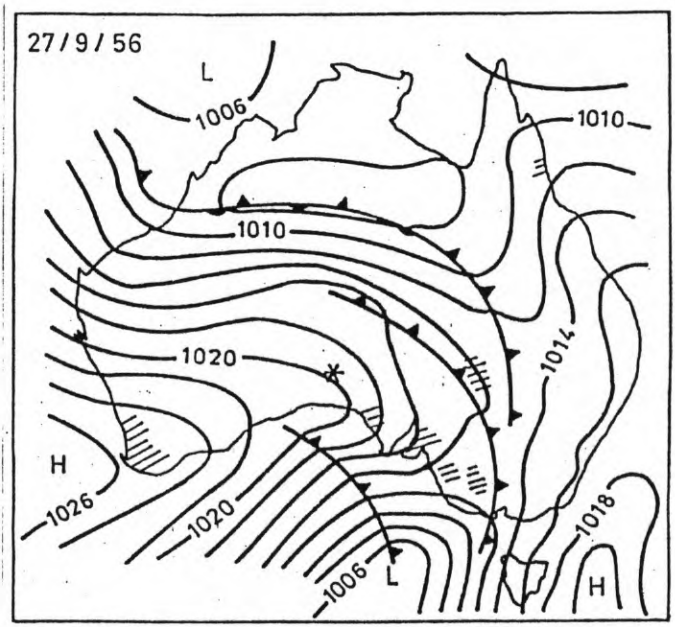
(b) a certain amount of wind shear must occur, although the precise spread is not specified;

(c) no rain within 500 miles of Ground Zero.

The first of the Buffalo Series, Buffalo 1 was fired at 1700 CST on 27 September 1956. The actual medium range fallout for Buffalo 1, greatly exceeded the firing contamination criteria. The wind structure hodograph indicated a minimum of shear between 15000 and 40000 feet. The cloud top reached 37500 feet nearly 10000 feet higher than predicted. The greatest concentration occurred in a Swathe 100 to 300 miles wide across the continent from the bomb site to the east coast.

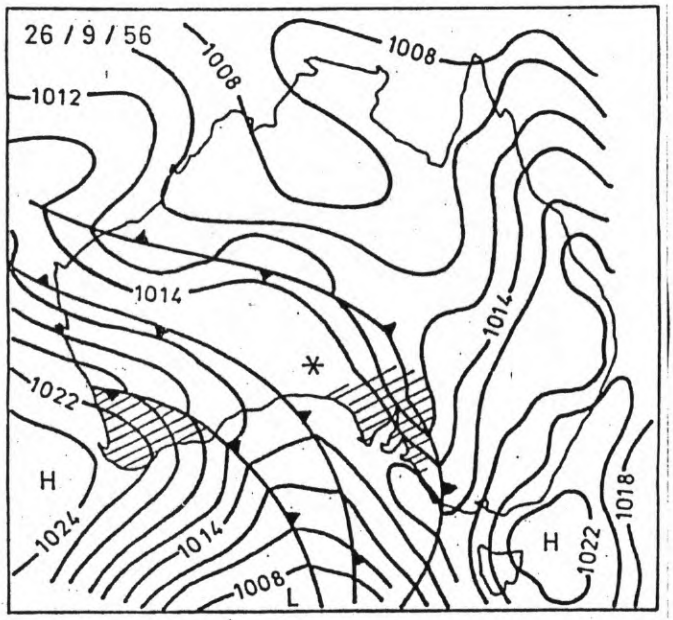
The Royal Commission reached the conclusion that Buffalo 1 was fired at a time when the predicted fallout was in violation of the firing conditions agreed to by the Government. The absence of a change in direction with height about 15000 feet was the basic reason for this violation. Figure 9 shows the weather map about two hours prior to firing time. A fresh southwesterly air stream is moving into the area from the Bight. One cold front has passed the site and a second one is approaching.

Figure 9. M.s.l. synoptic chart for 1500 local time 27 September 1956



An interesting account in the press was written by the well known English science reporter, Chapman Pincher, concerning the conditions which preceded the firing of Buffalo 1. Pincher reported a near disaster on the preceding day. All was set for firing when a last minute balloon ascent raised doubts in the minds of Sir William Penney and the safety experts. 50 minutes before firing time the winds shifted drastically. If this had happened an hour later the bomb might have been fired and the whole of Maralinga Village contaminated. Pincher concludes in his report "the weather men who have every possible scientific aid in the exercise were confident that the blast would take place on schedule according to information given us at 5a.m., shortly after we touched down at Maralinga. Yet within one and a half hours their forecasts were hopelessly adrift. A study of the weather map for 1500 CST the preceding day Figure 10 shows that the firing of the test must have been something of a gamble. With a series of cold fronts approaching from the southwest there could have been repeated changes of the wind, both prior to and subsequent to the passage of the fronts.

Figure 10. M.s.l. chart at 1500 local time on 26 September 1956, the day on which the firing of Buffalo 1 had been planned.



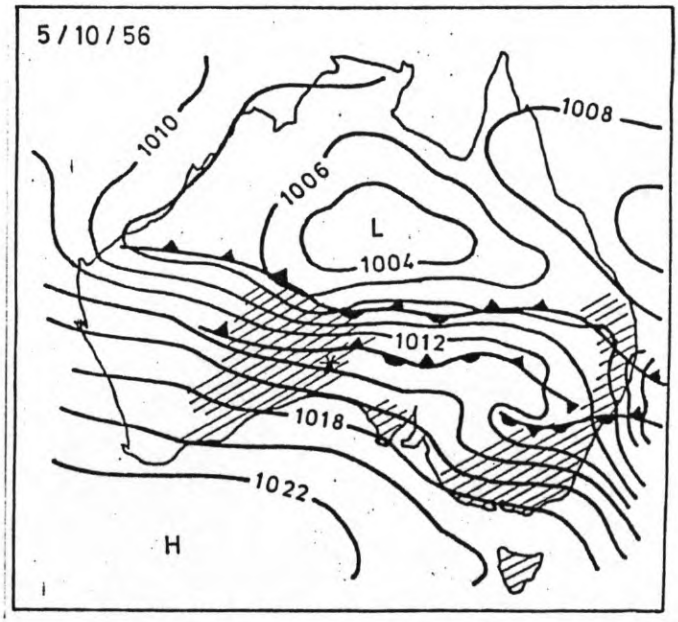
Buffalo 2 was fired on 4 October 1956 at 1630 CST. The overall fallout for this test was heaviest relatively close to Maralinga and down to the Bight with relatively high concentrations over a wide area swinging up to the SA-NSW-Qld border then across northern NSW to the coast. The wind criteria were met, but the rain criteria were not.

Isolated thunderstorms were forecast for areas of South Australia north and east of the test site. Clearly this was not remote nor more than 500 miles from Ground Zero as specified in the various criteria. Shortly before firing, the natural cloud cover increased considerably. No rain was produced by the bomb itself but rain subsequently fell to the northwest of the test site. Washout by rain was probably responsible for the fallout to the south and southeast of Ground Zero.

The Commission concluded that Buffalo 2 was fired in conditions which violated

the firing criterion that there should be no forecast of rain except in areas remote from Ground Zero. Rain was forecast within 250 miles and actually fell within 100 miles of Ground Zero. Figure 11 shows the weather chart for the following day, about 22 hours after firing time. The shaded area shows where precipitation fell during the previous 24 hours. This was by no means an easy situation upon which to base a forecast of required accuracy with two quasi-stationary fronts lined east-west along the isobars.

Figure 11. M.s.l. synoptic chart for 1500 local time on 5 October 1956



Buffalo 3 was fired at 1530 hrs local time on 11 October 1956. This firing created some controversy because of the advection of fallout over Adelaide. Radioactivity was also detected in Melbourne, Hobart and Sydney, but slightly greater fallout occurred over the Adelaide area than over other major cities.

The top of the cloud reached 15000 feet. The Royal Commission Report states that "the wind changed soon after the explosion and veered from southwest to northwest. This meant that the cloud was blown to the south and some fallout from 6000-7000 feet fell over the Maralinga Village about 10 hours after the firing". For this round there was no problem with rain.

The yield was only 3 kt, relatively small, so the wind criteria at firing were met. However, only 15 minutes after firing time the surface wind had changed from 269° 06 knots to -15° 03 knots. Figures 12 and 13 show the weather maps for D and D + 1 days, Buffalo 3. It is clear that in this case the anti-cyclone moved rapidly east. The steering thermal wind of the 1000-500 mb thickness chart would probably have indicated this. The surface geostrophic wind at Maralinga on 12 October is northerly and the upper winds would have been northwesterly ahead of the approaching trough. This could have been foreseen, and the fallout over Adelaide avoided.

Figure 12. M.s.l. synoptic chart for 1500 local time on 11 October 1956

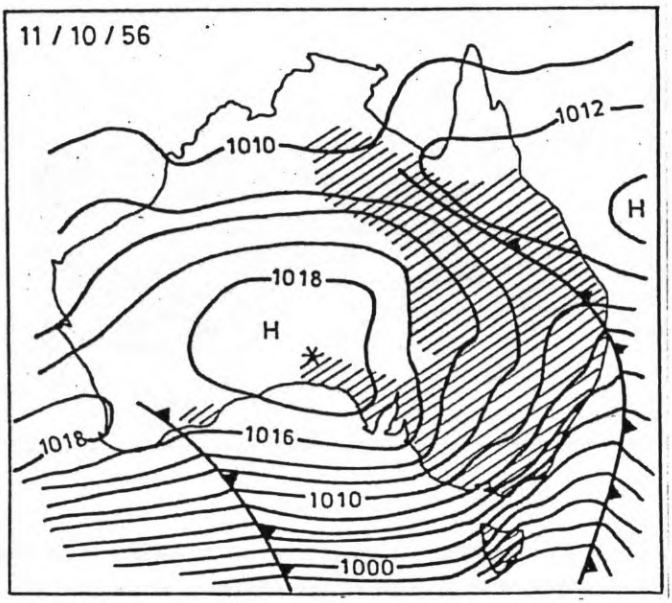
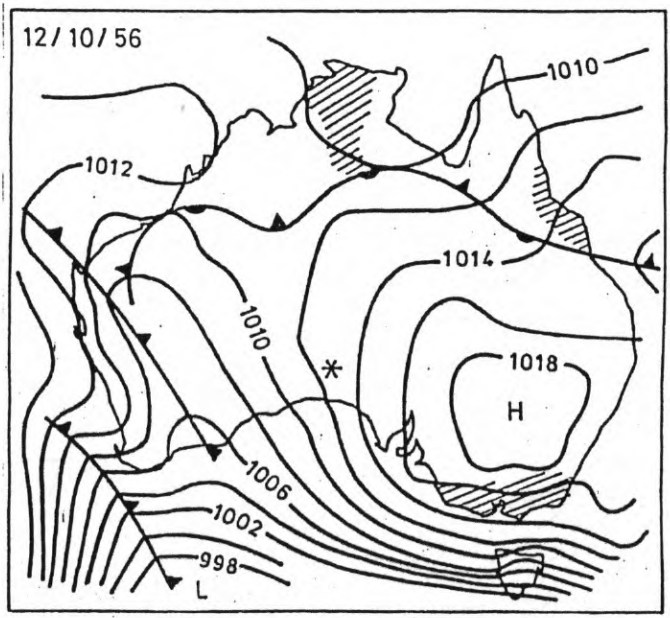


Figure 13. M.s.l. synoptic chart at 1500 hrs local time on 12 October 1956

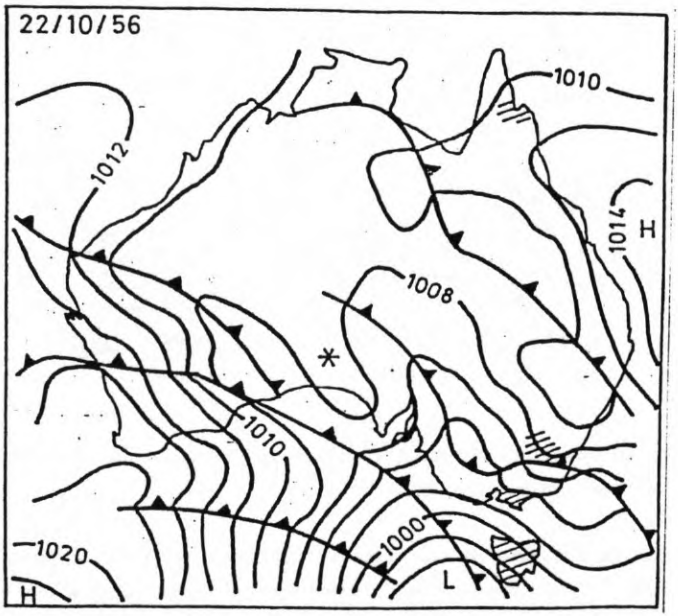


The Royal Commission concluded that Buffalo 3 should not have been fired under the conditions prevailing at the time.

The final shot of the Buffalo series, Buffalo 4 was fired at 0005 hrs on 22 October 1956. Conditions had been favourable on the preceding day but that had been a Sunday and a Sunday firing was not acceptable to the Australian Government (although it was, of course still Sunday in Western Australia, so this seems to have been a somewhat artificial restriction). This was the only bomb which was exploded at night and it is wondered what information could have been obtained in the dark, particularly since it was reported that a sheet of low stratus cloud moved in shortly before the firing and prevented visual ground observations of the cloud development.

The heaviest fallout occurred in an area from the site over to the north-eastern sector of South Australia. About seven eighths of the continent, northeast of a line from about Shark Bay to Gippsland received measurable fallout. Figure 14 shows the weather map at 1500 hours on 22 October. The synoptic situation is extremely complicated upon which to base a forecast of the required accuracy.

Figure 14. M.s.l. synoptic chart for 22 October 1956 at 1500 hrs local time, 15 hours after firing time.



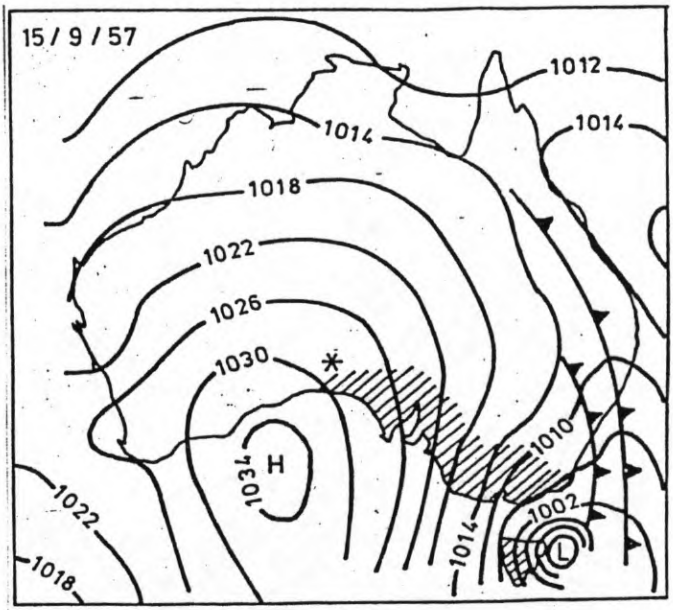
The Royal Commission concluded that Buffalo 4 was fired under conditions for which the fallout was predicted to exceed Level A beyond a distance of 100 miles and into the inhabited region. In addition, there was overlap exceeding Level A beyond 100 miles with fallout from Buffalo 1.

The final series of tests, the Antler series were conducted a year later in 1957. Antler 1 was fired at 1430 hours on 14 September, on the third attempt.

The cloud rose to 9500 feet. On this occasion weather conditions were considered almost ideal because an inversion limited cloud height and with winds below cloud top level carried the cloud away from rain areas to the east and southeast of the continent. In this case the yield was less than a kiloton.

Figure 15 shows the weather map 24 hours after firing. The fallout was directed northwards towards less highly populated areas. The weather map explains this with the strong anticyclone centred to the west of the Bight and its axis orientated north south allowing a southerly geostrophic wind on its eastern flank. The Royal Commission did not make any serious criticism of this firing although comment was made that due to a 15° discrepancy in the swathe of the fallout plume, sticky paper ground monitoring stations to measure local fallout were placed in the wrong locations.

Figure 15. M.s.l. synoptic chart 24 hours after the firing of Antler 1.



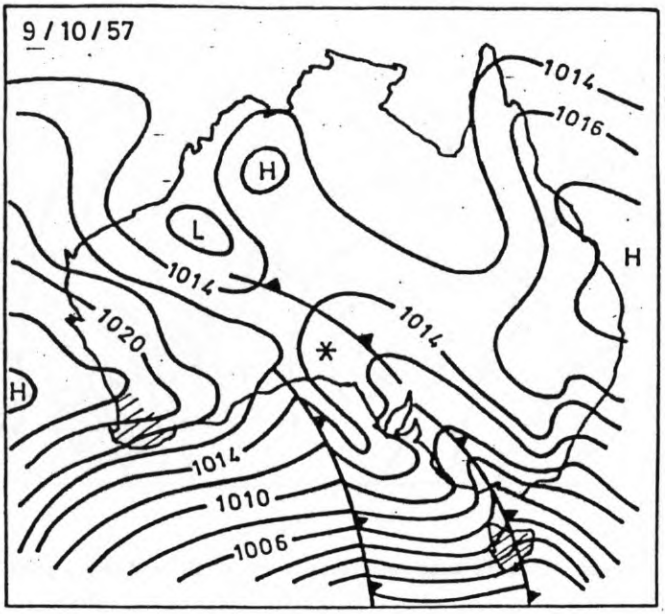
Antler 2 was fired at 1000 hrs local time on 25 September 1957. The cloud

reached 24000 feet, nearly 10000 feet higher than predicted. Fallout occurred over the central and northern part of the whole continent. The greatest intensity fell in a band extending about 500 km northeast from the test site with pockets of high intensity on the northeastern Queensland coast and the New England region in New South Wales. In this case, if the cloud height had been correctly predicted prior to firing, the calculated fallout pattern would not have satisfied the safety criteria for firing.

The Royal Commission concluded that for Antler rounds 1 and 2 the measured contamination from fallout satisfied the criteria set for those rounds. However, the Commission also concluded that the criteria adopted for the Antler tests allowed about double the contamination levels approved by the Government for the Buffalo series a year before.

Antler 3, the last of the series and of the whole operation of tests was fired at 1615 hrs local time on 9 October 1957. Figure 16 shows the weather map for 1500 hrs 9 October, the approximate firing time. Fallout occurred over most of

Figure 16. M.s.l. symoptic chart at approximate firing time of Antler 3 on 9 October 1957.



the eastern half of the continent, and on Adelaide, Melbourne, and Sydney. The closest rain, however, was about 100 miles south of the nearest forecast trajectory.

The Royal Commission, in this case, concluded that the fallout at the edge of the "inhabited" zone exceeded the limit of radioactivity criterion. The intermediate distance fallout for Antler 3 was seriously underestimated.

CONCLUSIONS

The clear impression and strong feeling with which one is left after studying the meteorological implications of the series of trials is twofold. Firstly, the ideally acceptable conditions were very infrequequent. They included restrictions of wind blowing from wide sectors, yet the wind in the permissible sectors had to possess substantial wind shear in direction, conditions which to some extent were opposing each other. No rain was to fall within defined ranges of distance. Secondly, there was always a political and human urgency to get the bombs fired. There were specific time deadlines involved in the whole program. Winds had to be forecast accurately, and from these winds the Theoretical Predications Group had to estimate air trajectories and fallout patterns. Also, the height reached by the bomb had to be forecast. The latter prediction was often in error. (see Table 2) After the Hurricane trial there was a distinct tendency to underestimate the bomb cloud height, and this must have led to errors in the predicted fallout values.

Table 2 Predicted and Actual heights reached by the bomb cloud tops.

TRIAL	ACTUAL HEIGHT (FEET)	PROBABLE PREDICTED	ERROR IN FORECAST
HURRICANE	11600	25000	+13400
TOTEM 1	15000	15000	0
TOTEM 2	20000	20000	0
MOSAIC 1	24000	17500	-6500
MOSAIC 2	47000	34000	-13000
BUFFALO 1	37500	27900	-9600
BUFFALO 2	13000	13000	0
BUFFALO 3	15000	16100	+1100
BUFFALO 4	hidden by stratus	30000	—
ANTLER 1	9500	9000	-500
ANTLER 2	24000	14600	-9400
ANTLER 3	23000	28300	+5300

The major meteorological errors were:

1 The choice of October (or any month for that matter) as suitable for Hurricane and Mosaic.

2 The firing of Totem 1 in conditions of small wind shear such that fallout was unduly concentrated.

3 The firing of Totem 2 in unstable conditions, the results of which were a gamble. Washout probably occurred over Adelaide.

4 The firing of both Mosaic G1 and G2 did not take account of Port Hedland winds which were different in the lower layers from those at the Monte Bello site.

5 The firing of Buffalo 1 in conditions which violated those agreed with the Government due to lack of sufficient wind shear and an underestimate of the height of the bomb cloud.

6 The firing of Buffalo 2 in conditions when rain occurred in areas too close to Ground Zero.

7 Buffalo 3 should not have been fired since fallout occurred over Adelaide.

8 The Buffalo 4 firing violated fallout levels and overlap areas which had been agreed.

9 The Antler 3 firing seriously underestimated intermediate distance fallout.

Only Antlers 1 and 2 escape criticism. Antler 1 was less than a Kiloton and even then the Commission did not seem wholly happy since the criteria laid down for the Antler series allowed a greater level of contamination than for Buffalo, a year before. Several of the Buffalo and Antler trials were carried out on the basis of forecasts made from unduly complicated synoptic weather chart patterns. Such forecasts contained a high factor of uncertainty.

Thus, in every one of the 12 major firings some fault can be found in the decisions to fire under the specific weather conditions that were prevailing at that time.

Could all of this have been avoided?

The following are some personal comments. They should not be construed in any

way as a criticism of the individual forecasters who took part in the operation.

The main fault in the meteorological service appeared to be an organizational one. That is to say, the operation was not given the highest priority in providing the best possible and top level scientists, as was the case with the nuclear physics aspect of the project. In consequence of this, the staff supplied were not at the highest level of expertise available, and as a very important correlative, they did not have the status nor authority to play an active role in the decision making process. At best, they acted as lukewarm advisors, probably unaware for much of the time of the political ploys that were going on continually behind the scenes.

The briefing and chief meteorologists for the Monte Bello and Emu Operations were British Naval officers, and although no doubt respected as such, they were not the best scientific brains in the country for the task - the latter were serving in the British Meteorological Office not in the Naval Weather Service.

Subsequent to Mosaic, the policy was adopted to allow the host country to supply the weather forecast advice. This was in accordance with general post-world War II international policy that all airports in the world should provide flight forecasts from their own National Weather Service resources manned by their own nationals. This was what was done at Maralinga. It may have been a palliative to satisfy Australia while keeping most technical aspects of the bombs themselves secret and withholding much other information. But the operation was so important with regard to the protection of life and health that a case could have been made for a high power joint meteorological task force with substantial authority. Since the firing decision was made by top British scientists, highly respected and senior U.K. Meteorological Office synoptic meteorologists might have carried more weight before the "heavies" than relatively junior Australian forecasters, in ensuring that all firings complied with the rigid safety criteria, and that no gambles were taken.

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